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AERO/SPACE ENGINEERING

REVIEW OF CURRENT AND FUTURE TRENDS IN AIRCRAFT • MISSILES • ROCKETS • SATELLITES • SPACECRAFT

IAS TO ADMINISTER
Louis W. Hill SPACE TRANSPORTATION AWARD... p. 32

OCTOBER | 1958

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On our cover

McDonnell Aircraft Corporation's F4H-1, the Navy's first supersonic two-place (includes radar operator) twin-jet fighter, is said to have the longest range and greatest fire power of any Navy fighter. It will carry air-to-air missiles and also is capable of conventional and nuclear bomb delivery. The aircraft, which recently completed its 65th test flight, is powered by two General Electric J79 engines of 15,000 lbs. thrust each. All-weather day or night operation at above Mach 2 speeds is reported by McDonnell. Outstanding contributions to the plane's development were made by two IAS Members: Albert Utsch, Chief Engineer, Airplane Engineering Division, and Herman D. Barkey, Senior Project Engineer. A tail view of the F4H at left shows its complement of missiles.

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AERONAUTICAL ENGINEERING REVIEW

AERO/SPACE ENGINEERING

VOLUME 17 / NUMBER 10 **October 1958**

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Milton Rogers, Air Force Office of Scientific Research — **34** Aerothermoelasticity
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Karel J. Bossart, Convair—Astronautics — **44** Departure and Return in Interplanetary Flight
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Lloyd E. Hackman, North American Aviation, Inc. — **53** Loss of Torsional Stiffness Under Load
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Computers and components

Radar

Ground support equipment

Test equipment

Control systems and components

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IAS News Notes

October 1958

$5,000-$10,000 SPACE AWARD. News on the largest monetary award for scientific achievement available through any scientific society may be found in the editorial on page 32 in this issue.

MAURICE ROY (F), Director, l'Office National d'Etudes et de Recherches Aeronautiques (ONERA), will give the Wright Brothers Lecture in Washington, D. C., Dec. 17. Mr. Roy was ICAS Executive Committee Chairman. His talk will cover French research in aerothermoelasticity, materials, structural flutter, combustion, air intake at supersonic speeds, experiments with ram-jets at high altitude, high lift devices, dynamic stability of aircraft and missiles, and the form and visualization of certain types of flow.

NEW EDITOR of Aero/Space Engineering is Allan Bernhardt. Formerly Associate Editor, he succeeds Welman A. Shrader, who will devote full time to duties as Director of all IAS publications.

WILLIAM LITTLEWOOD, 1957 IAS American Honorary Fellow, was named the Daniel Guggenheim Medal winner for 1958. He is Vice-President - Equipment Research of American Airlines. The story appears on page 25 of this issue.

A SPECIAL 8-page pictorial story on the ICAS Congress in Madrid, September 8-13, will be featured in the November issue of Aero/Space Engineering.

NATIONAL MEETINGS CALENDAR

Oct. 7-8	Canadian Aeronautical Institute-IAS Joint Meeting, Chateau Laurier, Ottawa, Canada.
Nov. 6-7	National Specialist Meeting on Dynamics and Aeroelasticity, Texas Hotel, Ft. Worth. Sponsored by Texas Section.
Dec. 17	Wright Brothers Lecture, Natural History Building Auditorium, Smithsonian Institution, Washington, D. C. French aeronautical research will be discussed by Maurice Roy.
1959	
Jan. 26-29	Twenty-Seventh Annual Meeting, Astor Hotel, New York. Honors Night Dinner, Tuesday, January 27.
Mar. 5-6	Flight Propulsion Meeting (Classified), Hotel Carter, Cleveland.
June 15-18	National Summer Meeting, Los Angeles, California.
Oct. 5-16	Seventh Anglo-American Aeronautical Conference, New York, N. Y.
Oct. 29-31	National Midwestern Meeting, Wichita, Kansas.

THE FIFTH ANNUAL EDITION of first-prize papers by IAS Student Members has been published by the Institute through the MINTA MARTIN AERONAUTICAL STUDENT FUND. The 127-page volume, "1958 First Award Papers," contains 11 top technical papers given at this year's IAS Regional Student Conferences. The volume has been mailed to Sections, Student Branches, Faculty Advisors, and Corporate Member Representatives. Individual requests for copies will be honored while a limited supply lasts.

WORTH $7,300 over a two-year period, the IAS FLIGHT TEST ENGINEERING FELLOWSHIP is open to U.S. citizens who have a Bachelor's degree in engineering by June 1959. For applications, write: Flight Test, IAS, 2 E. 64th Street, New York 21, New York. See next month's magazine for more details.

SECTION MEETINGS CALENDAR

Oct. 7	Wichita: Dinner Meeting, McConnell AFB Officers Club. (Social at 6:30, dinner at 7.) "Methods of Upper Air Research Using Balloons" by R. A. Carlson.
Oct. 8	Baltimore: Classified Meeting, Westinghouse Air Arm Division, dinner at 6:30, lecture at 8. "ARPA and the Military Space Program" by H. F. York.
Oct. 14	Los Angeles: Specialist Meeting, IAS Building, 8 p.m. "Electrical Power in the Space Age" by J. H. Huth.
Oct. 14	Tulsa: Dinner Meeting, Alvin Plaza Hotel. (Social at 6:30, dinner at 7.) "Celestial Mechanics Involved in a Lunar Impact" by G. C. Goldbaum.
Oct. 16	Los Angeles: Dinner Meeting, IAS Building. (Social at 6, dinner at 7.) "Technical Management Problems Associated with Aircraft, Missile, and Satellite Programs" by Edgar Schmued.
Oct. 21	Washington: Dinner Meeting and Air Show, Davidson Field, Ft. Belvoir. (Social at 6, dinner at 7:30.) "The Army's Air Mobility Program" by Brig. Gen. Richard D. Meyer, USA.
Oct. 22	Chicago: "Operational Problems of Jet Aircraft" - time and place to be announced.
Oct. 24	Texas: Dinner Meeting, Western Hills Inn, Highway 183. (Social at 7, dinner at 8.) "Tactical Air Command" by H. Reese Ivey.
Oct. 28	Los Angeles: Specialist Meeting, IAS Building, 8 p.m. "The Physical Mechanism of Boundary-Layer Oscillation" by R. Betchov.

JOINT MEETINGS CALENDAR

Apr. 5-10	1959 Nuclear Congress, Municipal Auditorium, Cleveland.
May 25-27	National Telemetering Conference, Cosmopolitan Hotel, Denver. Sponsored by IAS, ARS, ISA, and AIEE.
June 11-13	1959 Heat Transfer and Fluid Mechanics Institute, University of California, Los Angeles. Cosponsored by IAS.

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IAS News

. . . a record of people and events of interest to Institute Members

"Zero to Infinity" Keynotes National Summer Meeting

THE 1958 National Summer Meeting drew some 1,400 members to 3 days of technical sessions and an all-day field trip in Los Angeles, Calif., July 8 through 11. The meeting emphasized the wide range of the aeronautical profession's interests and responsibilities in the flight spectrum from "zero to infinity."

A total of 17 technical sessions were held simultaneously over the first 3 days and 2 evenings at the Ambassador Hotel. Three of the sessions were classified Confidential, and three were Secret.

The meeting, which featured 71 speakers and drew a record registration of 1,366, covered commercial and military aircraft, missiles, space flight, and engineering and scientific education. Two luncheons with major speakers, the banquet, and a visit to the Douglas Long Beach Division for a tour of DC-8 production facilities and a display of turbine transports rounded out the program.

Technical subjects included aerodynamics, structures, electronics, propulsion, and test facilities. The complete development stories of the Thor missile, the Convair B-58 supersonic bomber, and the Lockheed JetStar were presented. There also were sessions on astronautical education, the role of management in aeronautical progress, and the current status of commercial turbine transports.

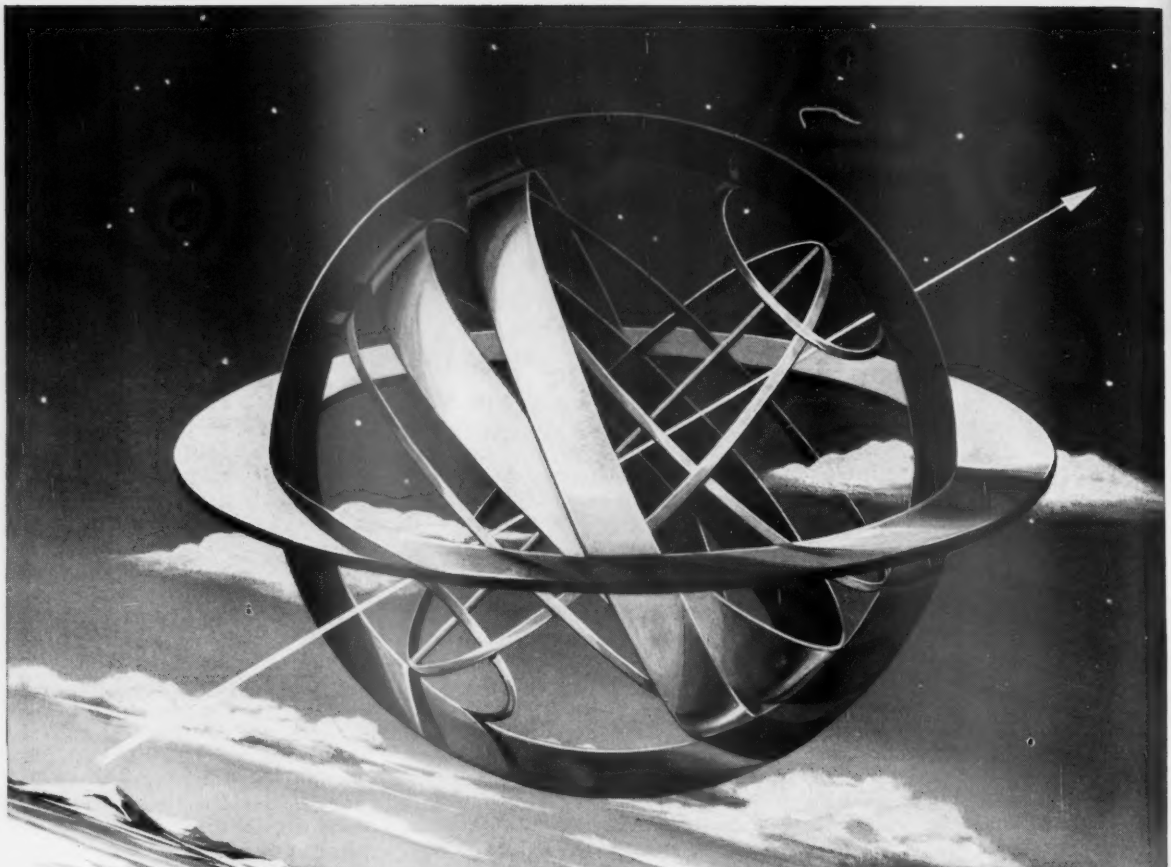
The opening-day luncheon speaker, July 8, was Dr. Frederick E. Terman, Provost and former Dean of Engineering, Stanford University. Dr. Terman, speaking on "Trends in Engineering Education," cited the relatively recent increase in the number of college-trained engineers who continue for advanced degrees.

Proposed changes in the top management structure of the Defense Department's research and development effort were outlined by Richard E. Horner, Assistant Secretary of the Air Force for Research and Development. He delivered the luncheon address on July 9.

After the technical sessions, a capacity audience of more than 900 attended the banquet in the Ambassador's Cocoanut Grove on July 10. Principal banquet speaker was Dr. H. Guyford Stever, Chairman, NACA Special Committee on Space Technology, and an IAS Vice-President. In his talk, "A Space Technology Program for America," Dr. Stever put the space exploration efforts of this country in historical, political, and economic perspective, with the aims and needs of mankind. A principal point of his discussion was that the aeronautical industry must and can assume a dominant role in the conquest of space.

On July 11, 400 members visited Douglas Aircraft Company's DC-8 production facilities and a display of commercial turbine transports. The group was welcomed by Donald W. Douglas, Jr., President, Douglas Aircraft Co.

Much of the credit for the success of the meeting goes to the IAS Los Angeles Section, chairmanned by M. Carl Haddon, and the IAS Western Region Staff, managed by E. W. Robischon. Los Angeles section members who contributed to the meeting include C. R. Cantrell, Chairman, Summer Meeting Committee; Program Chairman D. A. Justice; H. R. Saffell, Chairman, Security Committee; and E. W. Thrall, Chairman, Membership Committee. The classified sessions were cosponsored by the ARDC Regional Office in Los Angeles, commanded by Col. E. O. Ney and represented by Don Darling and Kurt Raynesford. The session on astronautical education was cosponsored by the American Society of Engineering Education, Aeronautical Division, chairmanned by Major V. S. Haneman, Air Force Institute of Technology.



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A panel discussion on Economic, Sociological, and Technological Factors of Space Exploration was undertaken by the scientists seated left to right: A. C. Hall, D. N. Michael, Morton Alperin, Homer J. Stewart, and Theodore von Kármán.

200 Expected, 650 Show at 'Local' Space Meeting

Meeting Sponsored by IAS San Diego Section, ARS, and ARDC Draws National Interest

by William H. Dorrance

More than doubling anticipated attendance, about 650 aero/space scientists and engineers attended a 2-day Space Exploration Regional Meeting in San Diego, August 5, 6. Sponsors were the IAS San Diego Section, its ARS counterpart, and the USAF Air Research and Development Command.

Though planned to interest some 200 local members of the societies and ARDC personnel, registrants appeared from all over the nation. Highlights included a panel discussion on Economic, Sociological, and Technological Factors of Space Exploration. Three technical sessions featured 18 papers.

Panel members were Theodore von Kármán, AGARD; Homer J. Stewart, California Institute of Technology; Morton Alperin, AFOSR; D. N. Michael, Dunlap and Associates; A. C. Hall, The Martin Co.; and C. L. Critchfield (moderator) of Convair. They answered in many ways "Why go in for space flight?" and, in general, speculated on its impact upon man and his way of life.

E. R. van Driest, North American Aviation Missile Development Division, chaired the August 5 afternoon session at which the following papers were heard:

"Materials for Space Flight" by G. A. Hoffman, The RAND Corp. Dr. Hoffman concluded that material strength close to atomic bond strength could be obtained by using nearly perfect crystal filaments, or "whiskers." If ways can be devised for both fabricating metal whiskers and incorporating them into structures, it will be possible to reduce airframe structure weights by up to 80 per cent.

"A Review of the Current Status of Satellite Attitude Control" by R. E. Roberson, North American Autonetics Division. Dr. Roberson reviewed the characteristics of several satellite attitude control systems. The physical bases for the systems are well established, he said, but much needs to be done with specific satellite applications.

"Space Propulsion Systems" by M. U. Clauser, The Ramo-Wooldridge Corp. Dr. Clauser discussed implications in the development of ion rockets and rockets whose gases are heated by fission reactors and thermonuclear reactions.

"Power Supply Problems in Ion Propulsion" by A. L. Heubner and R. H. Boden, North American Rocketdyne Division. The implications of using various liquid metals as heat exchange fluids in nuclear-powered ion rockets and the cooling radiator size problem and its relation to reactor power output were discussed by Dr. Huebner.

"Measurements on Explorers I and III" by Phyllis Buwalda, Caltech Jet Propulsion Laboratory. Mrs. Buwalda reported on the intense radiation found at altitudes above 600 miles.

"Application of Relativity in the Determination of Trajectories of Space Vehicles—Part I, Gravitational Shift" by A. R. Hockstim, Convair. Clocks on spaceships will beat at a different rate from clocks on earth, therefore, radio signals from earth will arrive at the spaceship and be measured at different frequencies than those at which they were transmitted on earth. If the frequency of transmission had been agreed upon, then the spaceship-measured frequency shaft is a measure of the spaceship position in the gravitational field.

"Antenna Problems in Space Communications" by M. G. Chatelain, Convair. A metallic spiral printed on the surface of a plastic balloon, used as a dipole or slot antenna, was suggested by Dr. Chatelain to economize in weight and maximize frequency bandwidth. There always would be a turn of the spiral corresponding to the incoming wavelength wave, he said.

"Accuracy Requirements for Trajectories in the Earth-Moon System" by H. A. Lieske, The RAND Corp. He discussed the precision navigation problem of choosing appropriate trajectories for vehicles leaving earth, circling the moon, and returning to earth.

Krafft A. Ehricke, Convair, moderated the August 6 morning session at which the following classified papers were read: "The Air Force Rocket Engine Program" by Col. D. D. McKee, Director, Astronautics, HQ ARDC; "The X-15 Research Airplane Program" by W. C. Williams, NACA High Speed Flight Station; "Space Exploration Plans" by J. DeNike, The Martin Co.; "Aspects of the Exploration of Mars and Venus by Means of Artificial Comets" by K. A. Ehricke; and "Navy Research Leading to Space Exploration" by Rear Adm. J. T. Hayward, Assistant Chief, Naval Operations, R&D.

John E. Naugle, Senior Staff Scientist, Convair Scientific Research Laboratory, chaired the August 6 afternoon session where the following papers were read:

"A New Concept in Flight Simulation" by J. D. Hardy, M.D., Naval Air Development Center. Dr. Hardy described results of tests on pilots "flying" in a simulated cockpit mounted on a 50-ft. centrifuge that is programed through prescribed loads by a tie-in with an analog computer.

"Radiation Effects on Living Tissue" by J. E. Cook, D.V.M., Holloman AFB. Dr. Cook described the use of mice in capsules lifted to 80,000 ft. to study effects of cosmic radiation on nerves and tissue. The impact of low-energy heavy nucleii (carbon through iron) upon living flesh and blood has been studied by the Air Force since 1953 in an attempt to gather conclusive statistical evidence.

"Closed Ecological Systems" by Lt. B. Pinc, ARDC Bio-Astronautics. Lieutenant Pinc discussed the many ramifications

Mr. Dorrance is Assistant to the Director of Scientific Research, Convair Division, General Dynamics Corp.

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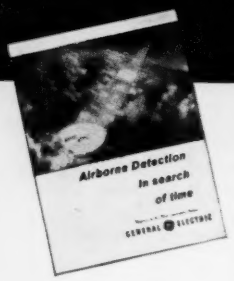

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of the effects of space environment upon man.

"Profile of Manned Space Flight" by C. M. Whitlock, M.D. Dr. Whitlock systematically analyzed the environment to which a space man will be exposed and, using this data, determined those ground test facilities best suited to test man in that environment.

"Radiation Intensity in Space" by Chairman Naugle. Dr. Naugle concluded the meeting with a review of the findings of an intense radiation region above 600 miles altitude.

The unclassified sessions were held at the Marine Corps Recruit Depot auditorium; the classified session and banquet took place at the El Cortez Hotel. Meeting General Chairman Richard Linnell and his colleagues were responsible for the successful program.

William Littlewood to Receive 1958 Guggenheim Medal

The Institute's 1957 American Honorary Fellow has been named recipient of The Daniel Guggenheim Medal for 1958. William Littlewood, Vice-President of Equipment Research, American Airlines, Inc., was the unanimous selection of the Medal Board of Award.

Mr. Littlewood receives the distinguished honor "for leadership and continuous personal participation over a quarter of a century in developing the equipment and operating techniques of air transport."

Recognized as a leading air transport engineer, he has made basic contributions to many widely used commercial aircraft. His career in aviation began in 1927 with Fairchild Aircraft where he became General Manager. He joined American Airways in 1930, and, when the firm was reorganized in 1934 as American Airlines, he remained to become Chief Engineer 3 years later.

Mr. Littlewood is a member of the NACA Industry Consulting Committee and the ATA Engineering Committee, and he is also Chairman of the joint Committee on the Development of Proximity Warning and Collision Preventing Systems. He also serves as Chairman, Advisory Panel on Aeronautics, Office of the Assistant Secretary of Defense (Research and Engineering).

William Littlewood

The Guggenheim Medal is given annually by The Daniel Guggenheim Medal Fund, Inc., to honor persons who make notable achievements in the advancement of aeronautics. Presentation is sponsored by one of three societies: the IAS, ASME, or SAE.

AGARD to Discuss Impact of Space on NATO R&D

The Advisory Group for Aeronautical Research and Development (AGARD) will hold its Eighth General Assembly at Copenhagen, Denmark, on October 28. A round-table discussion on "The Impact of Space Technology on NATO Research and Development"—scheduled for the afternoon session—will highlight the meeting.

The impact of space flight on environment, materials, communications, and medicine will be analyzed by leading figures in these fields.

In addition, three AGARD panels—Combustion and Propulsion, Wind Tunnel, and Flight Test— will cosponsor a technical meeting on "Engine Test Facilities and Techniques" on October 23 and 24, also in Copenhagen.

This program calls for a consideration of propulsion system test requirements, ways of obtaining high-altitude test conditions, and papers on instrumentation and measurements of steady-state and transient conditions. The second day will be devoted to papers on scaling, component testing, engine flight testing, and, finally, to a paper on correlation of results obtained by all these methods.

After the panel meetings, distinguished representatives of Denmark and other NATO nations will present greetings to start off the General Assembly.

Navy Confers Award on J. C. Hunsaker

Jerome C. Hunsaker (HF), Professor Emeritus, Massachusetts Institute of Technology, has been presented with the Navy's highest civilian award, the Distinguished Public Service Award. (*Cont'd.*)

Meet the Staff

An Aero/Space Engineering feature on personnel of the Institute of the Aeronautical Sciences

Marjorie Rodé— "Miss Institute"

Marjorie Rodé joined the full-time staff of the Institute 17 years ago, at a time when its employees numbered but a fraction of the current work force. Today, she is Secretary and personal assistant to Institute Director S. Paul Johnston.

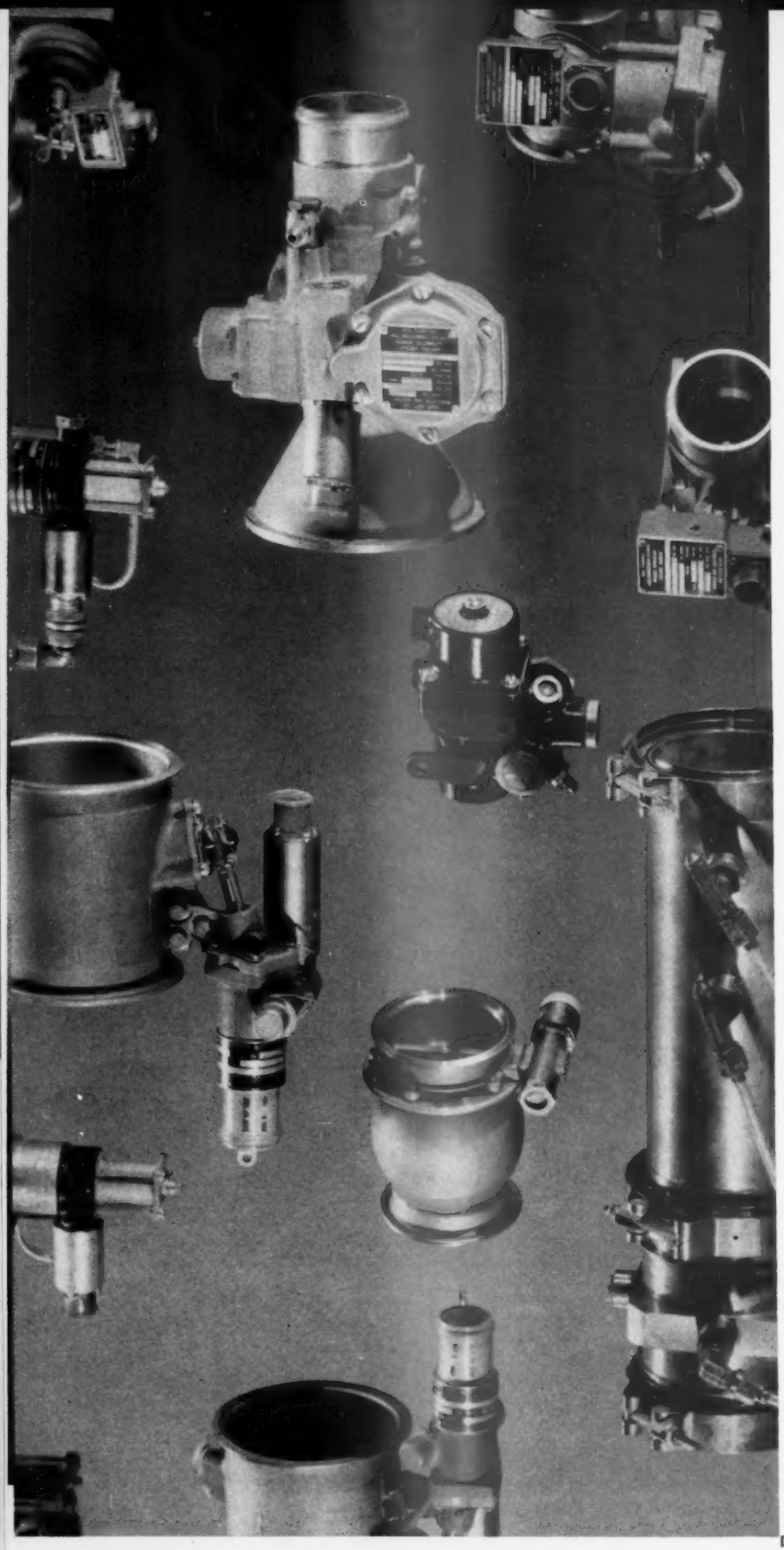
Miss Rodé became an employee in 1941 and performed general secretarial duties for the succeeding 3 years. In 1944, she became Secretary to the late Lester D. Gardner, who founded the Institute in 1932.

On Major Gardner's retirement in 1946, the present Director asked Miss Rodé to continue working in the same capacity. Her duties have grown with the Institute. She is, in effect, the Director's administrative assistant and also looks after certain personnel functions.

By far the most widely known and most traveled personality among Institute "distaffers," Miss Rodé has assisted with great tact and charm at many IAS national and regional meetings. Hers are the delicate tasks involving invitation lists and reservations—keeping track not only of "who's who" but "who's where!"

In recent years, with broadening of IAS interests on the International level, Miss Rodé's rare abilities in working with and among members of the scientific community have taken her all over this country, and occasionally abroad. Through her tact and skill, she made many new friends for the Institute during the huge Fifth International Aeronautical Conference in Los Angeles in 1955. She has served also at AGARD assemblies in Europe and in the United States. As this is being written, she is assisting with the First International Congress in the Aeronautical Sciences in Madrid, Spain (September 8–13).

A veritable storehouse of useful information about the IAS and its programs, Miss Rodé's devotion to the Society, its members, and its principles of service has won for her the title—bestowed with fondness by those who know—"Miss Institute of the Aeronautical Sciences."—A.B.



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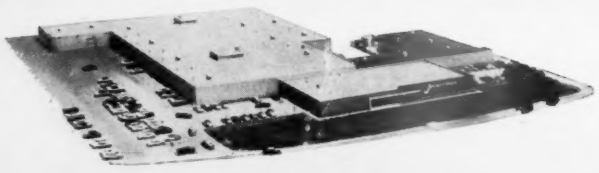

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A 1908 graduate of the Naval Academy, first in his class, Dr. Hunsaker was honored for "outstanding contributions . . . in the fields of scientific research and development."

The award was presented by Garrison Norton, Assistant Secretary of the Navy for Air, in the presence of Thomas S. Gates, Secretary of the Navy, Adm. A. A. Burke, Chief of Naval Operations, R. McPate, Marine Corps Commandant, and others.

Dr. Hunsaker has received other awards, including the Navy Cross, the RAeS Gold Medal, Guggenheim Medal, and the Presidential Medal of Merit.

Aviation Medicine Symposium Planned

The Fourth Annual Symposium in Aviation Medicine will be held at the University of California, October 22–24. The symposium is sponsored by the School of Medicine and the Department of Continuing Education in Medicine.

IAS members may obtain program information by writing to Mrs. Bettie Minifie, Assistant Head, Continuing Education in Medicine and Health Sciences, University of California, Los Angeles 24, Calif.

Air Force Honors F. E. Moskovics

The highest civilian honor of the Air Force was recently given to an IAS member for his contributions to the B-52 and J-57 programs.

Fredrick E. Moskovics (M) was presented with the Exceptional Civilian Service Award for his work as Special Consultant to the Commander, Air Materiel Command, from February, 1952, to June, 1954. He is an Industrial Consultant for A. O. Smith Corp.

Mr. Moskovic's citation reads, "Through his special studies of the B-52 and J-57 programs, he recommended production methods and materials which enabled manufacture in mass production at reasonable costs and estimated costs which were of vital importance in budgeting Air Force funds." The award was signed by James H. Douglas, Secretary of the Air Force.

Mr. Moskovics received the award at a luncheon held at the Engineer's Club, New York City.

General R. W. Rawlings (right), Commander, Air Materiel Command, presents the Air Force Exceptional Civilian Service Award to Fredrick E. Moskovics.

Doolittle Heads Space Laboratories

James H. Doolittle (HF), a former IAS President, will become Board Chairman of Space Technology Laboratories, according to an announcement from the parent company, The Ramo-Wooldridge Corp. He will take office on next January 1 when the Laboratories become a separate corporation.

The announcement said that Mr. Doolittle will continue as a member of the Board of Shell Oil Co. but will retire as a Vice-President of that company.

Necrology

William F. Durand

William F. Durand, an Honorary Fellow of the Institute who has been called the "dean of American engineering," died in New York on August 10 at the age of 99.

Dr. Durand was a major contributor to the sciences of hydrodynamics and aerodynamics for a period of 75 years.

The basic theories of propeller design were formulated by him, and he was the first scientist to conduct experimental research on propellers.

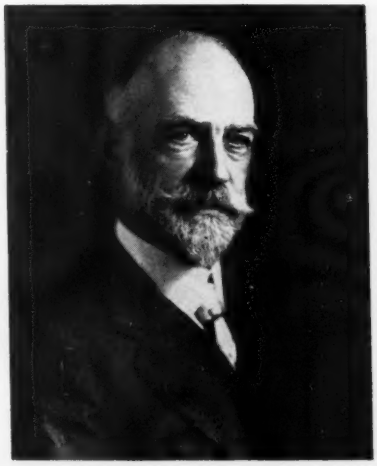
He was one of the original members of the NACA in 1915 and was Chairman during World War I. At the beginning of World War II, he was called out of retirement—at 82 years of age—to organize industry for the development of the jet engine and to head a special NACA committee for jet propulsion research.

Dr. Durand was graduated with honors from the U.S. Naval Academy in 1880. At that time, the Academy did not award degrees, however in September, 1956, he received a Bachelor of Science degree—75 years after his graduation.

He served in the Navy for 7 years and in 1887 began a 37-year span as an educator. He taught at Michigan State, Cornell, and Stanford, where he "retired" in 1924, at the age of 65. At 68, he undertook his massive and definitive work "Aerodynamic Theory," a six volume compilation of the principles that control air and other gases in motion. During this same period, he also wrote a biography of Robert Henry Thurston, a pioneer in engineering education.

He also was interested in steam and hydraulic power and was a consultant in the design of the Hoover, Grand Coulee, and Shasta Dams of the U.S. Bureau of Reclamation.

William F. Durand



Dr. Durand was the first American invited by the Royal Aeronautical Society to deliver its Wilbur Wright Lecture. He also was the first recipient of the Wright Brothers Memorial Trophy, awarded by the National Aeronautic Association for "significant public service of enduring value to aviation in the United States."

He received many other outstanding honors including the Guggenheim Medal, one of the highest, for "notable achievement as a pioneer in laboratory research and theory of aeronautics and for distinguished contribution to the theory and development of aircraft propellers."

He received the Franklin Institute's Medal, the John J. Carty gold medal of the National Academy of Sciences, the ASME gold medal, and in 1948, the Presidential Medal of Merit, the highest civilian honor conferred by the U.S.

Dr. Durand was born March 5, 1859, at Beacon Falls, Conn.

Iven C. Kincheloe, Jr.

The Institute has received news of the death of Capt. Iven C. Kincheloe, Jr., USAF, (A), 1956 Mackay Trophy winner and one of three pilots scheduled to fly the X-15. The 30-year old Korean War ace was killed on July 26 in an F-104 take-off crash at Edwards AFB, Calif.

Holder of the American altitude record,

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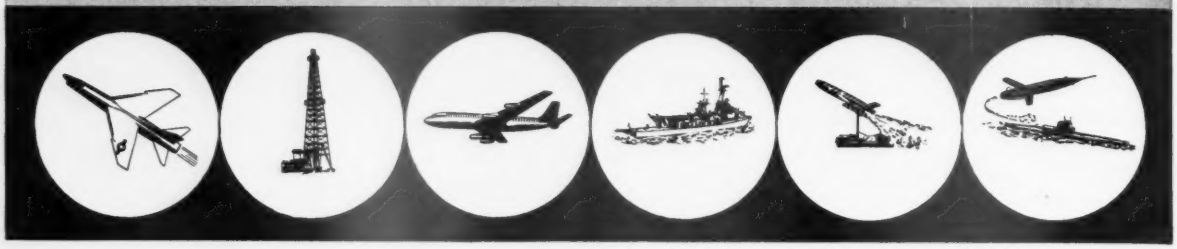

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"GOOD WILL" is the disposition of the pleased customer to return to the place where he has been well treated.
– U.S. Supreme Court

XUM

126,200 ft. in the Bell X-2, Captain Kincheloe was an aeronautical engineering graduate of Purdue University. He entered the Air Force from the Air Reserve Officers Training Corps program at Purdue and received his wings in 1949. He flew 101 combat missions in Korea during 1951 and 1952, becoming the tenth jet ace there and destroying eleven Communist planes. His medals include the Silver Star, Distinguished Flying Cross with oak-leaf cluster, and four air medals.

Less than a week after his death the Air Force announced the establishment of a scholarship fund at Purdue in his honor. The scholarships will be for basic research in aeronautics and astronautics.

James A. Looney

The Institute has learned of the death of 1st Lt. James A. Looney (A), an Air Force Flight-Test Engineer at Edwards AFB, Calif. He was 29.

Lt. Looney was the project engineer in charge of setup, performance, and evaluation of flight-test programs.

He was graduated from Massachusetts Institute of Technology with a B.S. in aeronautical engineering in 1952. He received his M.S. degree from M.I.T. a year later.

Born in Philadelphia, Pa., he made his home in West Roxbury, Mass.

Jurio Tsuchiya

The Institute has received news of the death of Jurio Tsuchiya (M) on June 28. Mr. Tsuchiya, 35, had been Research Aerodynamicist, Aerophysics Department, Mississippi State University.

His research contributions include high lift through distributed suction boundary-layer control, programing for a digital computer, Imai's method for pressure distribution, several technical papers on this subject, and a paper on programing von Kármán's method for pressure distribution on a body of revolution.

Mr. Tsuchiya received a Master of Mechanical Engineering degree from Kyoto University in 1945. He was an assistant in the Kyoto Mechanical Engineering Department for a year before becoming lecturer and finally Professor of Engineering at Shiga Prefectural College. He held this post until 1950. In that year and until 1954, he was a Research Fellow on the staff at Shiga.

He came to Mississippi State in 1954 to do research in the dynamics of real fluids. Last January he received a Master's degree in Mathematics from that school.

Besides being affiliated with the IAS, he was also a member of the Soaring Society of America, Society of Aeronautical Engineering of Japan, and the Japanese Institute of Mechanical Engineers.

Attention Members!

All members of the Institute are invited to submit material concerning their activities for publication in the "News" columns of *Aero/Space Engineering*.

IAS *News* — *News of Members*

Kenneth P. Bowen (M) has joined The Sierracin Corp. of Burbank, Calif. as Assistant to General Manager. He formerly was Vice-President, Manufacturing and Materiel, Northrop Aircraft Co.

Thomas Courtney Jr., (M) has joined Temco Aircraft Corp. as Chief Project Engineer. He formerly was Project Engineer, Guided Missile Division, McDonnell Aircraft Corp. He also has served on the Institute's Advisory Board.

Kenneth F. Hallinan (A), formerly Manager, Defense Products Sales, American Machine & Foundry Co., has been appointed Sales Manager, Western Region, AMF's Government Products Group.

James E. Hayes (M), formerly Senior Structure Engineer in the Research and Analytical Methods Group, Convair—Fort Worth, is now with the University of Oklahoma Research Institute as Research Engineer, specializing in fatigue of metals and structures.

Howard M. McCoy (AF) has been named Assistant to the Executive Vice-President, Marquardt Aircraft Co. He formerly was the Washington Representative, Propeller Division, Curtiss-Wright Corp.

George F. Metcalf (AF) has been elected to the newly created office of Regional Vice-President—Washington Defence Activities, General Electric Co. He formerly was General Manager, Missile and Ordnance Systems Department, Philadelphia, Pa.

Angelo Miele (M), Purdue University, has delivered a lecture on **"Lagrange Multipliers and Quasi-Steady Flight Mechanics"** at the Institut für Flugmechanik of the Deutsche Versuchsanstalt für Luftfahrt, at Mülheim, Germany.

Eugene M. Gluhareff (M), President, E. Gluhareff Helicopter Corp., is shown tether-testing his firm's single-blade helicopter, the MEG-1X. Mr. Gluhareff reports the experimental, propane-fueled vehicle is powered by a tip-jet engine. The firm recently moved from Manhattan Beach to Palm Springs Airport, Calif.

Adm. James S. Russell (F) has been sworn in as Vice-Chief of Naval Operations. He formerly was Deputy CINC and Chief of Staff, Atlantic Fleet.

Walter R. Woodward (M) has been advanced from Chief Engineer to Director of Engineering at Dynametrics Corp., Burlington, Mass.

IAS *News* — *Corporate Member News*

• **Aerojet-General Corp.** has announced the election of six vice-presidents: Bernhardt L. Dorman, Test Engineering; Richard D. Geckler, Solid Rocket Plant, Sacramento, Calif.; William I. Gore, Customer Relations; Chester A. Hill, Assistant Treasurer; William L. Rogers, Azusa Operations; and John S. Warfel, Avionics. The firm also announced that a new field service office has been established at Douglas Aircraft Co., Tulsa, Okla., with R. L. Lobo assigned as Resident Representative in charge of all Thor-Able Program operations with which Aerojet is involved.

• **Aeronca Manufacturing Corp.** has announced the appointment of John Schwinn as Assistant to the President.

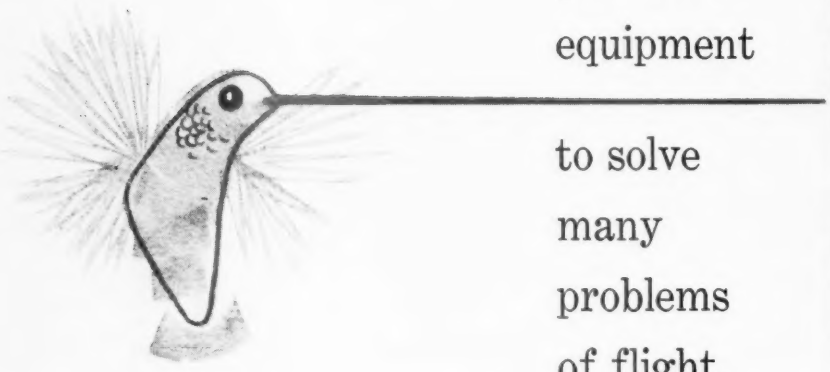
• **Aeroquip Corp.** has opened a new 10,000-sq.ft. plant and offices at Dallas for assembly, proof test, and inspection of hose assemblies. Roger H. Leuba has been named Manager, Aircraft Operations, and Clyde Stratton, Plant Manager. Address is 9105 Sovereign Row, P.O. Box 35463, Dallas, Tex. The firm also announced the appointments of Robert W. Bowman as corporate Vice-President in charge of organization planning, and Fred W. Schwier as General Sales Manager, Jackson Division.

• **Allis-Chalmers Manufacturing Co.** has announced the following appointments: Y. S. Bogg, Manager, Tampa, Fla., district office; Ralph L. Haney, Manager, Philadelphia district office; and Charles E. Dandois, Manager, Allentown, Pa., district office. The firm also announced formation of district offices at Miami and Jacksonville.

• **Aluminum Co. of America** reports that the largest application of aluminum in the United States will be in the construction of the Air Force Academy which will use more than 5 million lbs. of the metal when completed.

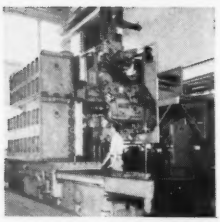
• **American Airlines, Inc.,** has announced that orders for 50 additional jet airliners have been placed: 25 Boeing 707-023 and

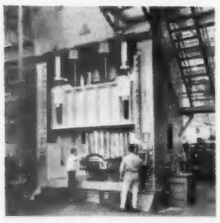
(*Continued on page 110*)

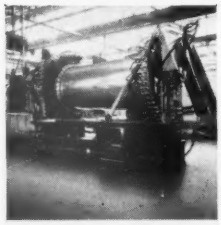


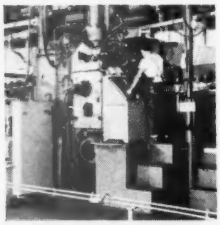
It takes
precision
equipment

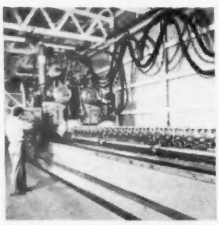
to solve
many
problems
of flight.

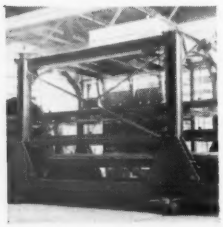












Rohr is famous for being first with the latest manufacturing tools to solve production problems of many aircraft parts. And when there is no special machine to mass produce a special part . . . Rohr is first in knowledge and know-how to design and build or adapt machines to make components better, faster and cheaper.

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DATELINE world

PROFESSIONAL NOTES AND REPORTS

Engineering and Scientific Briefs from Correspondents Around the Globe

U.S.S.R. Scientists Work on Unique Memory Device

◆ An article in *Promyshlenno-Ekonomicheskaya Gazeta* for January 19, 1958, announces that U.S.S.R. scientists are working on the development of a new type of large-capacity memory device operating on the same principle as the human brain. In the article, L. Gutenmakher, Doctor of Technical Sciences and a U.S.S.R. pioneer in the development of computing machines, states that ". . .our scientists are attempting to develop a 'machine memory' which would possess the same properties (as the human brain) and which can store about the same volume of information and produce it according to the principle of the association of ideas." The type of the electronic device is not disclosed. The only descriptive details given are that it "has no mechanically moving parts and, in contrast to magnetic tape, films, or gramophone records, can reproduce a recording without mechanical displacement of the machine's parts. This makes it possible to reproduce a recording an unlimited number of times, even for a hundred years." The main purpose of the new memory machine appears to be, not the storing of intermediate results of computations, but rather permanent storage and a fast read-out of the vast amount of information accumulated in human experience and contained in "hundreds of millions of books."

The article states that results of the latest U.S.S.R. works indicate that a machine called "telelibrary" (telebiblioteka) will be developed which can be used simultaneously by numerous subscribers directly from their homes or offices. It appears probable that this device is some kind of electronic large-capacity memory having rapid selection and read-out combined with wire-operated television. Gutenmakher mentions that in June, 1957, an experiment was performed whereby several pages of text, recorded by the long-time "machine memory," were transmitted from one Moscow district to another by the city automatic-telephone network. "On the television screen," he says, "it was possible to read the sharp image of the text." Theoretically, by simply typing the title of a book on a keyboard, the future subscriber will receive almost instantaneously, either visually or orally, the desired information from the text. The machine will not only store information, it is said, but it will also be able to "ask for help" from incorporated computing devices which would solve, by logic, on the basis of stored information, certain problems related to the question. Special high-speed machines will be necessary for processing the information in books, magazines, and archives into the form suitable for use by the "machine memory."

Gutenmakher compares the importance of the new development to that of printing. He calls this development especially important for raising the productivity of intellectual work through better access to, and recall of, previously accumulated knowledge in all fields of science and engineering.

First Electronic Brain Being Readied in Poland

◆ The Polish press announced in May that the Polish electronic brain for mathematical calculations should be operational by the end of the year. The "XYZ" electronic brain contains only 400 electronic tubes, while similar devices perfected in other countries need 1,000, it is asserted. The machine can "remember" about 500 numbers which it will be able to employ in calculations. Contemplated addition of more magnetic parts will eventually increase the "memory" of the brain to about 8,000, according to the announcement.

Petroleum and Plastic Mixed in Soviet Solid Fuel Experiment

◆ The Fuels Research Institute, Academy of Sciences, U.S.S.R., has published a report on experiments with a solid fuel consisting predominantly of petroleum. The petroleum is mixed with a special type of plastic, subjected to high pressures, and compressed into cubes. These cubes contain up to 95 per cent fuel and are protected against evaporation by a thin coating. The solid fuel can withstand great variations of temperature and is impervious to moisture. Before use it is reliquefied.

Soviet "Little Bee" Makes Maiden Flight

◆ The Soviet general-purpose monoplane Pchelka (Little Bee), designed by O. K. Antonov, made its first flight on March 16, 1958, according to a United Press dispatch from Moscow, which credited the Soviet trade-union newspaper *Trud* as the source of the information. The item indicates a passenger capacity of five and states that the high-wing, twin-engined aircraft has a maximum speed of 130 knots and can take off and land from a 240-ft. runway.

An announcement by the designer as long ago as a year (March 22, 1957) said that series production had already been started. However, a United Press dispatch quoting Radio Moscow in July, 1957, said that "a first test aircraft is now being built." It is possible that a photograph published in August, 1957, may have shown the aircraft before it was completed.

A Tass broadcast on February 12, 1958, said that the workshop tests of the aircraft would be completed in a few days and that the An-14 would be ready for flying tests. The same date, an article in the *Red Star* newspaper said that the first flight was scheduled for February 23, 1958. This was 3 weeks before the flight was actually made. The Moscow broadcast also said that the aircraft has two 260-hp. AI-14 piston engines and that, while carrying six passengers and 150 kg. (330 lbs.) of luggage, or a cargo of 600 kg. (1,320 lbs.), the Pchelka can fly 600 km. (325 nautical miles) with a maximum speed of 230 km. hour (125 knots). Radio Moscow had previously said it would have a "high altitude range" and be "able to fly the clouds if necessary."

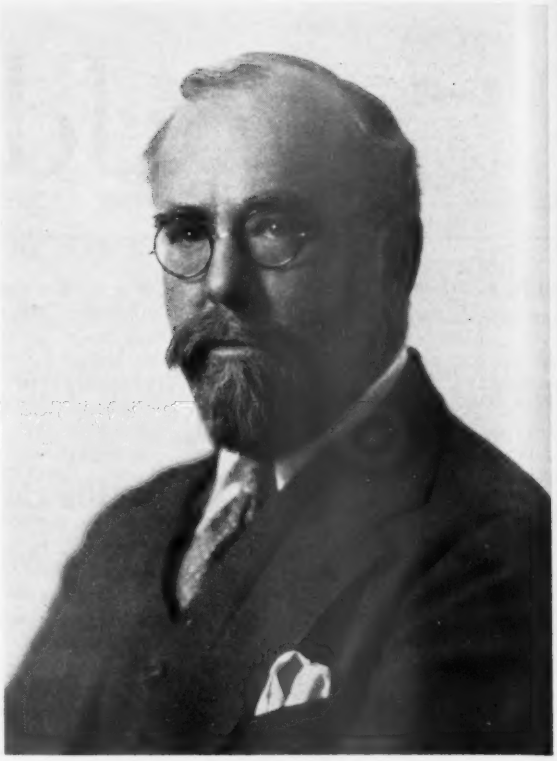
By variations in translations, the impression has sometimes been given that the An-14 is a helicopter or a VTOL aircraft. Actually, the designer has said that it "resembled a helicopter in its take-off and landing qualities," and the Tass announcement claimed that it would be "cheaper to produce than a helicopter." In published photographs the An-14 more nearly resembles an STOL (short take-off and landing) aircraft. It apparently can accommodate 7 people, including crew.

XUM

EDITORIAL

For three generations the Hill family of Saint Paul, Minn., has backed the development of all forms of transportation—land, sea, and air. Now, believing that it is in the best interests of humanity to recognize and to encourage significant contributions indicative of American enterprise and ingenuity in the art and science of space flight, the Hill Family Foundation has established

THE LOUIS W. HILL SPACE TRANSPORTATION AWARD



Louis W. Hill

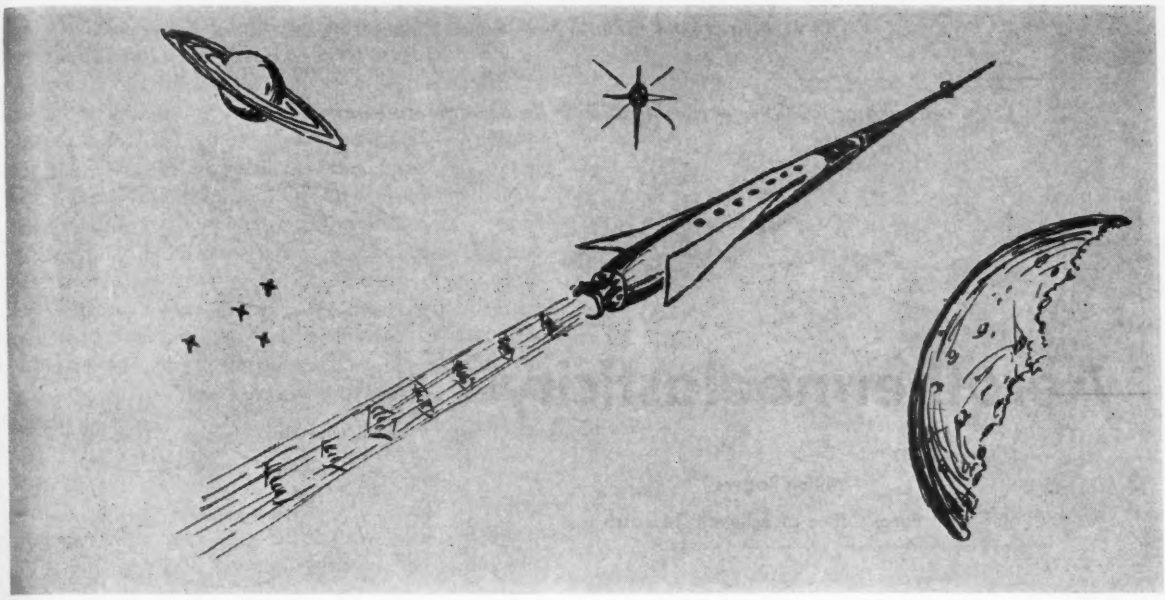
OXCART to SPACESHIP

In 1948, the year of Louis Hill's death, few people in this country gave serious thought to extraterrestrial travel. Certainly, anyone in those days who might have approached any of the established foundations for a grant to finance a trip to the moon would have been hastily shown to the door—if not locked up as a strictly unreliable character.

Times have changed. We haven't reached the moon yet, but a foundation whose founder and his family have had an interest in transportation that goes back to the days of the oxcart has recognized the long-range implications of space exploration for the human race. The Board of Directors of the Hill Family Foundation has established in the IAS a very substantial award to encourage space transportation for peaceful purposes.

At a recent meeting, the Board of Directors of the Hill Family Foundation adopted the following resolution:

"WHEREAS it is the considered judgment of the Board of Directors of the Louis W. and Maud Hill Family Foundation that it is in the best interests of humanity that encouragement and recognition be given to significant contributions indicative of American enterprise and ingenuity in the art and science of space flight and



"WHEREAS such an objective is in conformity with the Foundation's policy and program of encouraging and supporting fundamental research and the early application of new knowledge in behalf of the welfare of mankind, now,

"BE IT RESOLVED that the officers of the Foundation be and hereby are authorized to enter into an arrangement with the Institute of the Aeronautical Sciences, Inc., New York City, New York, for the purpose of establishing, for a minimum of five years, an annual Louis W. Hill Award for the Outstanding Contribution to Space Transportation; said Award program to incorporate the following provisions:

(1) The Award to be administered annually by the Institute of the Aeronautical Sciences, Inc., through a Board of Award consisting of seven highly qualified persons selected by the Institute and approved by the Foundation, said Board to be empowered to consider nominations and make the final determination of the recipient or recipients of the Award;

(2) The Award is to take the form of an honorarium of Five Thousand Dollars ($5,000) to an individual or up to Ten Thousand Dollars ($10,000) in the event of a "team" contribution, the exact amount of the latter to be determined by the Board of Award; in addition, a suitable engraved certificate is to be presented to the Award recipient, or recipients;

(3) The Award is to be made at the Honors Night Dinner of the Institute commencing with the dinner to be held in January 1960;

(4) Research in any or all of the fundamental sciences relating to space travel or space technology (e.g., take-off, navigation, environmental conditions, biological and psychological factors, re-entry, etc., etc.) shall be considered as suitable projects for consideration for the Award;

(5) The recipient or recipients of the Award must be citizens of the United States of America, residents of the United States, and employed by an American institution, scientific research organization, governmental service or by industry, or be engaged in independent research. . . ."

The suggestion that such an award be established was discussed by the Council of the Institute at its July 10 meeting in Los Angeles. Subsequently, the program was formalized as outlined in the preceding paragraphs and has been confirmed by the officers of both the Foundation and the Institute. The agreement is now in effect.

At a joint conference of the two groups, the following Board of Award was selected and approved:

Dr. Hugh L. Dryden, Deputy Administrator, NASA
Dr. Clark B. Millikan, Director, GALCIT
Dr. W. Randolph Lovelace, II, Director, Lovelace Foundation
Dr. H. Guyford Stever, Associate Dean of Engineering, M.I.T.
Dr. Athelstan F. Spilhaus, Dean, Institute of Technology, University of Minnesota
Dr. Fred L. Whipple, Director, Smithsonian Astrophysical Observatory, Harvard University
Dr. T. P. Wright, Vice-President—Research, Cornell University

It is planned that the Board of Award will meet shortly to consider eligibility, rules, procedures, etc. These will be announced at the IAS meeting in January. During the subsequent 12 months, candidates for the Hill award will be considered. As outlined above, the formal presentation will be made at the IAS Honors Night Dinner in January, 1960.

We of the Institute are particularly pleased to have been selected by the Hill Family Foundation to participate in this program. It not only constitutes the largest monetary award for scientific achievement available through any scientific society, but also recognizes the Institute's leadership in the ever-broadening areas of space science and space technology. In administering this award, we are in a position to provide tangible evidence of outstanding achievement, as well as kudos, to those who make major contributions to the science and art of space transportation.

S.P.J.

This exclusive contribution to Aero/Space Engineering
analyzes a field of coming importance and
presents intriguing problems for consideration by the scientific community.

Aerothermoelasticity

Milton Rogers
Air Force Office of Scientific Research

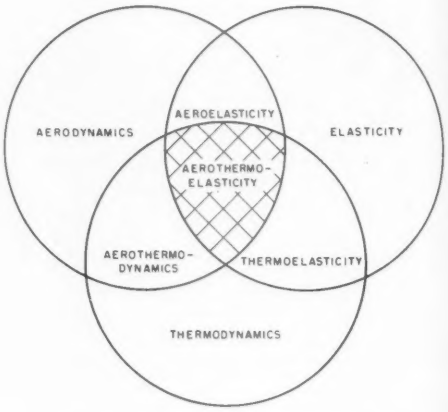


FIG. 3. Domain of aerothermoelasticity.

UNDER THE flight conditions and high speeds made possible by modern means of propulsion, the structural designer faces a situation quite unlike that faced by designers of subsonic airframes. In subsonic flight, airloads could be translated directly into stresses by means of the theory of elasticity based on the proportionality of stress and strain. Aeroelastic effects were generally regarded as secondary considerations; quick cures were the vogue when an airframe exhibited this "structural ailment." Because the laws of elasticity, or those of strength of materials, provided reliable guides to the approximate behavior of proposed airframe structures and because satisfactory structural materials were available, designers with experience and skill could practice their art with a large measure of confidence and a high degree of success.[1]

An indication of the flight boundaries envisaged for vehicles of the near future is given in Fig. 1. The range of flight speeds and altitudes considered possible for steady flight is indicated as a "corridor of continous flight," above which the lift (plus centrifugal force) is insufficient to support the weight of the vehicle and below which the vehicle becomes too hot because of aerodynamic heating.

When air flows at high speed over the surface of an airplane or missile in flight, the air close to the surface is heated by adiabatic compression and by viscous energy dissipation. This heat is communicated to the surface at a rate which depends upon many factors, such as the configuration and material of the vehicle, the velocity, the altitude, the time of exposure to the temperature, and the difference in temperature between the skin and the heated air. This constitutes the well-known aerodynamic heating problem and gives rise to the so-called thermal thicket or thermal barrier.

Fig. 1 shows that, if skin temperatures considerably in excess of an equilibrium temperature of 1,500°F. can be tolerated, there is no structural obstacle to the attainment of arbitrarily high flight speeds provided the altitude is appropriately chosen. The equilibrium temperature is defined as that temperature at which the heat loss due to radiation is exactly equal to the input of the heating source. Therefore, the beneficial effects of very high altitudes for very high speed flight are compounded since the higher the altitude, the greater the possible radiation cooling—i.e., radiation heat loss. If skin temperatures much in excess of 1,500°F. cannot be tolerated, then an upper limit to continuous level-flight speed exists which depends on the tolerable temperature level. It is interesting to note the small area of the corridor occupied by the present flight envelopes of all aerial vehicles, both military and research. When one considers the blood, sweat, and tears that went into obtaining an understanding and proficiency in handling the subsonic structural problems, one can appreciate the magnitude of the effort that will be required of present and future structural research.

In keeping with traditional subsonic analytical

Mr. Rogers is Chief, Mechanics Division.

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The opinions expressed herein are those of the author and not necessarily those of the Air Force.

trends in almost all investigations of the structural aspects of aerodynamic heating, considerable emphasis has been given to the loss of structural strength at elevated temperatures due to degradation in material properties, thermal stresses, creep, and fatigue. However, there are also questions which arise as to the effect of aerodynamic heating on aeroelastic phenomena. Corresponding to a loss of strength, there are reductions in stiffness and in vibration frequencies of the structure. These properties have a direct influence on all aeroelastic occurrences. The present paper will attempt to present and discuss some of the effects of aerodynamic heating on aeroelastic phenomena and to indicate the possible impact of this consideration on contemplated design practices.

Aeroelasticity

The term *aeroelasticity* is used to designate a class of problems in airframe design which deals with the mutual interaction of elastic forces with aerodynamic and inertial forces in an airplane or missile structure. Aeroelastic problems would not exist if airframe structures were perfectly rigid. It is the ever-present flexibility that is responsible for the various manifestations of aeroelasticity. As the speed and, consequently, the dynamic pressure increase, the flexibility of the structure plays an increasingly important role in design considerations.

Generally speaking, aeroelastic problems can be subdivided into two categories: *static* aeroelasticity, which deals with the interaction of only elastic and aerodynamic forces, and *dynamic* aeroelasticity, which deals with elastic, aerodynamic, and inertial forces.

Static aeroelasticity embraces, among others, such problems as load distribution on a flexible wing, wing divergence, control surface effectiveness, control surface reversal, and alteration of airplane and missile stability derivatives due to flexibility. Dynamic aeroelasticity deals with such problems as wing and control surface flutter, panel flutter, autopilot installation on flexible structures, vibrations of structures due to buffeting, and dynamic response of structures due to sharply applied loads (gusts, blasts, landing loads, gun reactions, abrupt control deflections).

The importance of structural flexibility in all of these aeroelastic problems is evident. In static aeroelastic phenomena, this flexibility enters directly into the problem, whereas in dynamic aeroelasticity, it generally appears in combination with the inertial properties as a vibration frequency ω. This vibration frequency ω is proportional to $\sqrt{k/m}$, where k is a measure of the stiffness, and m is a mass property of the structure.

Aeroelasticity has been the subject of intensive study during the past 20 years, and a considerable understanding of, and ability to predict, many aeroelastic phenomena has been achieved. Several good texts on this subject have recently appeared in the open literature.[2,3] It should be noted that for modern high-speed airframes, aeroelastic considerations have begun to dominate the overall design philosophy.

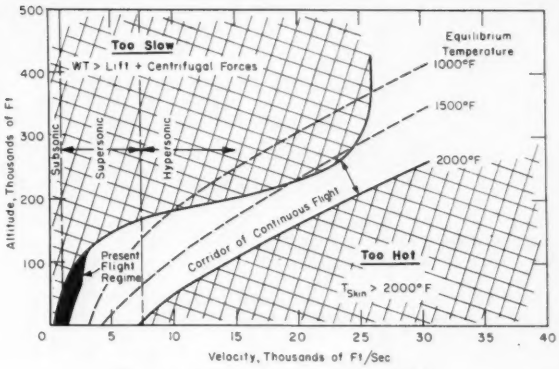


Fig. 1. Corridor of continuous flight.

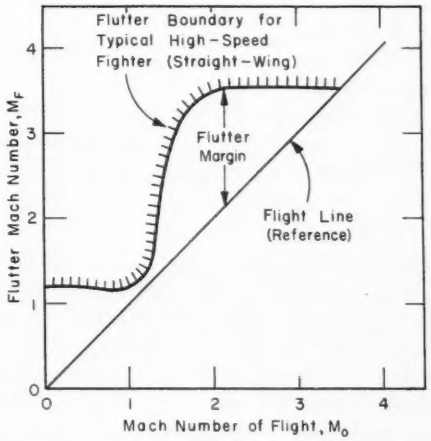

Flutter Boundary for Typical High-Speed Fighter (Straight-Wing)
Flutter Margin
Flight Line (Reference)
Flutter Mach Number, M_F
Mach Number of Flight, M_0

Fig. 2. Flutter considerations for typical fighter.

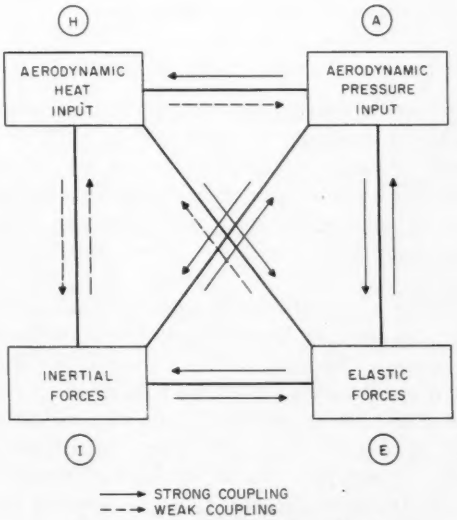


Fig. 4. Aerothermoelastic rectangle.

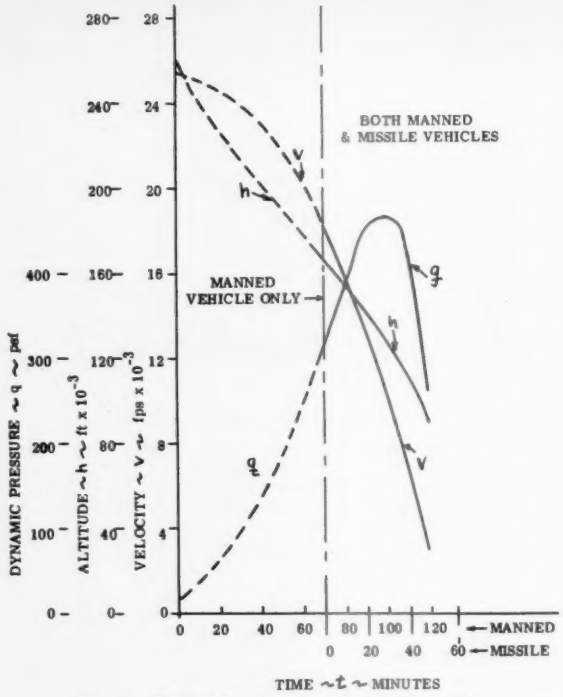


FIG. 5. Flight histories of typical glide vehicles.

This can be attributed in a large part to the increased flight speeds, which, on the one hand, have increased the aerodynamic forces available to excite aeroelastic phenomena, while, on the other hand, the use of thin wing profiles and slender bodies has placed an inherent limit on the ability of the designer to provide the adequate structural stiffness necessary to prevent undesirable aeroelastic behavior in high-speed flight. An illustration of the effect of increased performance on one aspect of aeroelastic behavior is given in Fig. 2. Needless to say, this increased performance similarly affects all other aeroelastic considerations.

AEROTHERMOELASTICITY

The introduction of aerodynamic heating adds still a further complication to aeroelasticity. The general problem of analyzing the behavior of an airframe—considering the mutual interaction between the elastic forces, aerodynamic forces, inertial forces, and the aerodynamic heat input—is called aerothermoelasticity. In analyzing the behavior of a deformable body under the simultaneous action of heat and force inputs, the engineer is thrust into the borderlands of aerodynamics, elasticity, and heat transfer (see Fig. 3).

Collar's well-known aeroelastic triangle has served as a good guide in charting the domain of aeroelasticity.[4] To orient our thinking concerning aerothermoelasticity, it is perhaps useful to extend the triangle to a rectangle as shown in Fig. 4. Here, another vertex representing the heat input to the system has been added to the original triangle. In general, there can be various degrees of coupling among all the four elements of this rectangle. The coupling among the elements A (aerodynamic pressure input), E (elastic forces), and I (inertial forces) is well known and forms the basis of the theory of aeroelasticity. The coupling associated with the element H (aerodynamic heating input) is new and has not yet been very well investigated.

It is apparent that the aerodynamic heating can have a significant effect on the elastic forces because of the deterioration of the properties of structural materials at elevated temperatures and the formation of internal thermal stresses arising from uneven thermal expansion of the structure. Other forms of coupling can be hypothesized. For example, it may be possible that the aerodynamic pressures can cause deformations of the wing such that the local angle of attack, and hence the resulting aerodynamic heating rates, can be significantly altered. Also, if the aerodynamic heat input is extremely rapidly applied and if the characteristic times of the aerodynamic heating system are nearly equal to the periods of the vibrational modes of the structure, a dynamic aerothermoelastic coupling is possible. Still another possibility is the thermodynamic coupling between the processes of heat generation and and elastic deformation which was first discussed by Lord Kelvin in the nineteenth century.[5] Ordinarily this thermodynamic coupling is negligible; however, there may be unusual conditions associated with flight at high speeds where it may become significant.

In most aerothermoelastic investigations, the mutual coupling between the elastic forces and heat-transfer processes is disregarded. Thus it is possible to divide the general aerothermoelastic problem into two separate problems—aerothermal and aeroelastic. The aerothermal problem encompasses the problems of thermal equilibrium and heat transfer between the airplane structure and the boundary layer, including the effects of radiation. The principal elements of this problem are strongly coupled, and the interacting effect between the boundary layer and the structure must be taken into account. Considerations of elastic deformations are ordinarily neglected. The end product of analysis of the aerothermal problem is a transient temperature distribution throughout the structure. The aeroelastic problem, on the other hand, as pointed out earlier, deals with problems of equilibrium between the aerodynamic, elastic, and inertial forces. There is strong coupling among these elements. However, feedback coupling between the aeroelastic and aerothermal problems is ordinarily neglected, and the sole effect of aerodynamic heating is to alter the elastic stiffness levels used in the aeroelastic analysis.

The division of the aerothermoelastic problem into two separate problems rests on at least three assumptions: (1) thermodynamic coupling between the processes of heat generation and elastic deformation is assumed negligible, (2) static aerothermoelastic coupling is small, and (3) dynamic aerothermoelastic coupling is small. Small static aerothermoelastic coupling implies that the total elastic deflections are insufficient to change the flow to an extent that the

temperature distribution, and hence the structural deflections introduced by the temperature distribution, are significantly altered. Small dynamic aerothermoelastic coupling implies that the characteristic times of the aerothermal system are long compared to the periods of the natural modes of the aeroelastic system.[6]

Although many aerothermoelastic problems may be approached in this uncoupled, two-stage manner, this may not always be a valid assumption, and the more general feedback couplings of aerothermoelasticity may have to be considered for certain cases.

Typical Boost-Glide Trajectories

To aid in better appreciation of the importance of aerothermoelasticity in future design considerations, one of the more promising vehicle types for hypersonic flight, the boost-glide vehicle, will be examined to see where and which aerothermoelastic problems may arise.

The boost-glide vehicle is impelled to a high altitude and hypersonic speed during a brief initial boost phase. It then glides without power along a flat-glide trajectory toward earth utilizing lift to efficiently convert its initial potential and kinetic energy into considerable range. The range attained is dependent on the lift to drag ratio. To obtain the lift, the vehicle must possess wings, and a slender body must be used to provide the best possible lift-drag ratios for gliding in the earth's atmosphere. The vehicle will probably utilize sharply swept delta wings with rounded or blunt leading edges to alleviate the local heating problem. Since the boost-glide vehicles must possess substantial lifting surfaces and bodies of fairly high slenderness ratios, this class of aerial vehicles will be more susceptible to aerothermoelastic problems than other hypersonic aerial vehicles such as ballistic missiles.

The speeds, flight times, and temperatures to be encountered by boost-glide vehicles are indicated by representative trajectory data, shown in Figs. 5 and 6, for two typical boost-glide vehicles which can accomplish the same military mission. One of these is representative of a manned vehicle, which is intended to be reusable by performing its mission and returning to base, whereas the other represents a missile which is intended to be a one-shot affair—i.e., expendable. It can be shown that either trajectory falls within the "corridor of continuous flight" of Fig. 1. It is to be noted in Figs. 5 and 6 that, because of the gliding nature of the flight, the trajectory of the missile is the latter portion of the trajectory for the much longer range manned vehicle.

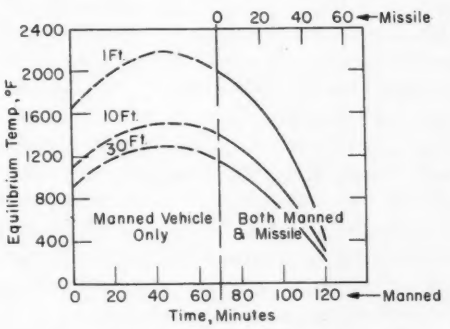
Several salient features regarding the differences between the two types of boost-glide craft can be extracted from the trajectory data. These differences are summarized in Table 1 and discussed more fully in the text below.

Since the manned aircraft must return to its base after accomplishing its mission, it requires more than twice the range of the expendable or one-shot vehicle.

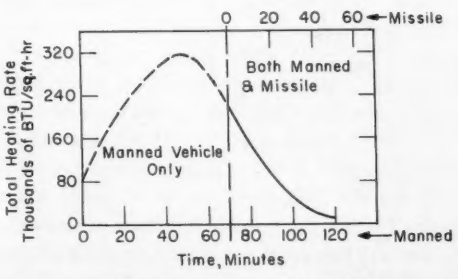
Table 1
Summary of Trajectory Differences

Manned (Reusable)	Missile (One-shot—expendable)
Trajectory Differences	
Long range (more than twice that of the missile)	Short range
Long flight (more than twice that of the missile)	Short flight time
Greater number of flights desired (reusability)	One flight desired
Presence of crew	No crew
Longer boost phase	Shorter boost phase (higher accelerations in boost possible)
Greater controllability required	No recall ability required
Higher equilibrium temperature	Lower equilibrium temperature
Ablation cooling unlikely	Ablation cooling possible
Results of These Differences	
More severe cooling problem	
More severe creep and fatigue problems	
High factors of safety	
Greater control and stability problems	
Possibly more erosion problems	

Hence the speed, altitude, and time duration of its flight are high compared to those of the missile. In addition, the manned type is exposed to higher equilibrium temperatures than the missile. As a result of exposure to higher equilibrium temperatures and to longer duration of flight, the actual skin temperatures (which lag behind the equilibrium temperatures because of the inherent "heat-sink" character of the structure, insulation, and cooling considerations) will also tend to be higher in the manned vehicle than in the missile. This will lead to more severe cooling problems for the manned type if one is to obtain structural and aerothermoelastic properties comparable with those of the



(a) Equilibrium Temp as a Function of Time



(b) Heating Rate as a Function of Time

Fig. 6. Thermal histories of typical glide vehicles.

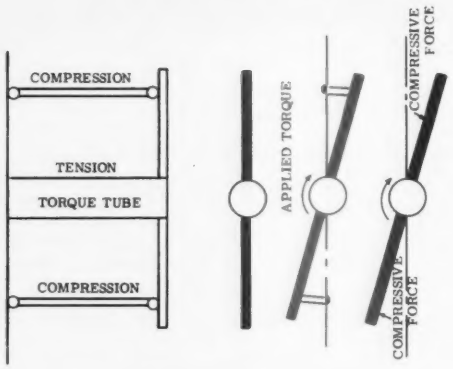


FIG. 7. Effect of thermal stress on torsional stiffness (taken from reference 7).

missile. It is to be noted that aeroelastic problems are most severe at highest dynamic pressure, q, whereas the most critical aerothermoelastic problems may occur at some other point in the trajectory because of temperature couplings and exposure time.

Further differences between the two types of vehicle which give rise to aerothermoelastic differences are the reusability feature of the manned vehicle, as well as the presence of a human crew.

The reusability feature of the manned vehicle leads to serious consideration of the problem of creep in structural design. Creep is always cumulative, and no relief can be obtained by any of the known processes of ex post exposure stress alleviation. The cumulative effects of creep and the corresponding shortening of the structural life of the airframe following each mission place a definite limit on the number of times a manned vehicle can be used when exposed to the temperature and load environment of a boost-glide flight. A somewhat related problem—namely, that of fatigue resulting from the recurring application of cooling and thermal stresses during each mission—also arises when considering the useful life of a manned boost-glide vehicle airframe. It might be mentioned that ablation cooling (cooling by allowing the outside structure to melt off) would not be as feasible in the reusable manned vehicle as in the expendable missile.

The presence of human beings in the manned vehicle will necessarily require higher factors of safety than the missile. The presence of human beings also will limit the accelerations permissible in both the boost phase and the final glide phase, thus exposing the manned vehicle to its environment longer than the corresponding missile. One of the more attractive features, from a military point of view, of placing a man in the boost-glide vehicle is the added mission flexibility obtained from the ability to recall or abort a mission economically after the mission has been initiated. This will, however, place greater demands on the maneuvering capabilities of the manned system if it is desired to alter significantly or drastically its trajectory during flight. This results in serious considerations of the effect of heat addition to the presently encountered aeroelastic degradation of control surface effectiveness.

Provision must also be made in the manned vehicle for maintaining the crew compartment sufficiently cool for the human occupant to perform effectively. This will result in thermal gradients and thermal stress distributions in the structure which, insofar as aeroelastic considerations are concerned, act to reduce the rigidity of the airframe.

AEROTHERMOELASTIC PROBLEMS

A number of aerothermoelastic problems common to both types of boost-glide vehicles of the previous section are discussed below. The discussion is based primarily on inductive reasoning, substantiated wherever possible by the few experimental and analytical results available to date. Moreover, the problems delineated below are not intended to be exhaustive but rather are chosen to represent and highlight some of the more important aspects of aerothermoelastic considerations.

Reduction in Torsional Stiffness

One of the most significant aeroelastic parameters in an airframe structure is the torsional stiffness of the wing and control surfaces. This is readily apparent since any change in twist angle affects the angle of attack and hence the airloads on the surface. Aerodynamic heating can significantly affect this torsional stiffness by two means. *First*, there is the reduction of the modulus of elasticity of the structural material because of the increased temperatures. *Second*, and more novel, is the reduction in stiffness resulting from the action of internal thermal stresses arising from the uneven thermal expansion of the structure.

As a structure heats up because of aerodynamic heating, some portions of the structure—for example, the outside surface—will be, at any instant of time, at higher temperatures than other portions. These higher temperature regions of the body would like to expand but are partially restrained by adjacent cooler portions. This results in compressive stresses in the higher temperature areas and tensile stresses in the cooler regions. The compressive thermal stresses and the attendant buckling phenomena are transient in nature since the temperature distribution is continually changing. Indeed, when a homogeneous structure eventually heats up to a uniform level, the thermal stresses, and the reductions in torsional stiffness resulting from these stresses, vanish.

The effect of thermal stresses on the torsional stiffness of a wing was explained by Dryden and Duberg[7] using the simple illustration shown in Fig. 7. A rigid crossbar is attached to one end of a torque tube that is fixed at the other end. In addition, the crossbar is joined to the foundation by means of a pinned bar attached at each end. Heat is applied to the end rods while the torque tube remains relatively cool; then, because of the constraining action of the rigid crossbar,

compressive forces develop in the rods while a tensile force, numerically equal to the sum of these compressive forces, is produced in the tube. If an external torque is then applied to the torque tube, as shown by the arrow in Fig. 7, the crossbar will rotate as indicated. However, the end rods are now inclined to their original position and the components of the compressive forces in the end rods act to produce a couple on the crossbar. Consequently, the torque tube is subjected not only to the externally applied torque but, in addition, to an extra torque arising from the compressive forces in the end rods. As a result, the twist of this idealized wing model is larger than it would be if compressive forces in the rods had been absent. In other words, because of the thermal compressive stresses at the ends of the cross section, the effective torsional stiffness of the structure has been lowered. Similarly, if the leading and trailing edges of a wing are at a higher temperature than the midchord (as is likely to occur with solid double-wedge sections), compressive thermal stresses will occur in the leading and trailing edges while the midsection is in tension. If an external torque is then applied to the wing, say by airloads, the compressive thermal stresses will have force components which produce an additional unstable torque, thereby resulting in greater torsional deflections than would occur in the absence of thermal stresses.

A simple home demonstration of the effect of the compressive stresses in the end rods on the torsional rigidity of a structure can be made using compressed springs instead of the solid heated rods.

The quantitative magnitude of the loss in structural stiffness due to thermal stresses can be calculated. Fig. 8 gives an indication of this effect for a solid double-wedge wing of high aspect ratio which is accelerated suddenly to a Mach Number of 10 and then maintained at this speed. The time history of torsional stiffness is shown in the upper plot. It is seen that the torsional stiffness decreases markedly during the early part of the flight while the wing is heating up and large temperature gradients and thermal stresses are, therefore, present. At later times, as the wing temperatures become more uniform and the thermal stresses vanish, the torsional stiffness rises again toward some steady-state value, which reflects only the reduction of the material modulus of elasticity at elevated temperature.

The wing torsional stiffness has a marked effect on a typical aeroelastic problem—namely, bending-torsion flutter of a wing. Bending-torsion flutter can be described as a dynamic instability involving the coupling of bending and torsional vibrations of a wing when placed in an airstream whose speed is greater than a certain value (the flutter speed for the wing).

The variation of this bending-torsion flutter speed corresponding to the change in torsional stiffness is indicated in the lower plot of Fig. 8. It is seen that, at some early time, the bending-torsion flutter speed may well drop below the flight speed giving rise to flutter, while, at some later time, the wing would stop fluttering if it were not already destroyed. It is interesting to observe that consideration of only the reduction in modulus of elasticity with temperature would not have provided a safe design for this specific case. The importance of these transient thermal stresses on general aerothermoelastic phenomena is apparent and has been the subject of several papers.[8,9]

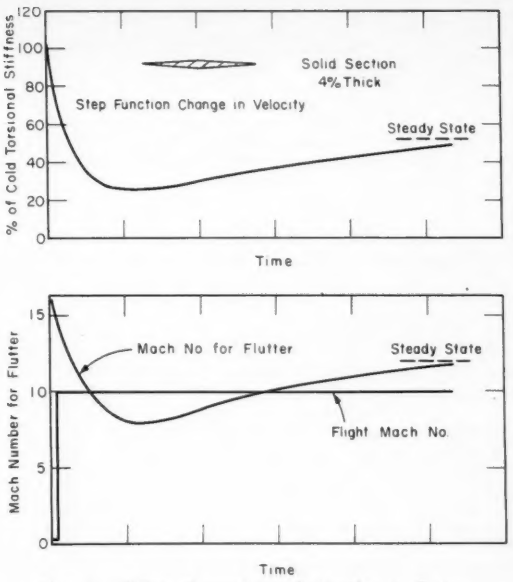


FIG. 8. Effect of aerodynamic heating on flutter.

Actual wing structures contemplated for hypersonic vehicles will tend to be of different planform and construction than the simple theoretical model considered here. The effects of thermal stresses on torsional stiffness carry over similarly to actual wings but perhaps with a lesser degree of intensity than that shown in Fig. 8. For example, a hollow built-up section will not have as severe a reduction in stiffness due to thermal stresses as the solid double-wedge section considered here. In any event, each particular geometry will have to be investigated individually to ensure that the torsional stiffness, under conditions of thermal stresses and reduced modulus of elasticity, remains adequate to prevent aerothermoelastic difficulties.

It might be mentioned in passing that the presence of plasticity and creep can lessen the thermal stresses developed in a structure, thereby making the stiffness changes less severe than would ordinarily be expected from an elastic thermal stress analysis. Of course, plasticity and creep may be undesirable from a strength of fatigue point of view.

Low Aspect Ratio Aerothermoelastic Problems

The most familiar and best understood static and dynamic aeroelastic problems are generally associated with higher aspect ratio configurations where wing torsional stiffness plays an important role. The use of low aspect ratio planforms, such as delta wings, has introduced the possibility of a more unconventional type of aeroelastic behavior associated with chordwise distortions and warpings of the wing surface. Even without the introduction of aerodynamic heating to

FIG. 9. A mechanism for aerothermoelastic coupling: The temperature on the lower surface is greater than the temperature on the upper surface.

the surface, these aeroelastic problems are quite complex and are not as clearly understood as their higher aspect ratio counterparts.

The introduction of aerodynamic heating to these low aspect ratio surfaces has produced some spectacular aerothermoelastic effects. The by now classic results of a series of experiments performed by the NACA at Wallops Island dramatically illustrate what may occur.[7] In these experiments, a square planform multi-web wing, cantilevered at one end, was placed at zero angle of attack in a steady airflow of Mach Number 2, having a stagnation temperature of 500° F. At first the wing showed no sign of distress. After a short length of time during which the structure heated, the wing suddenly exhibited a violent chordwise "flag-waving" type of flutter which soon resulted in destruction of the wing. A repeat of this test on a similar specimen under the same conditions, except with a stream stagnation temperature of 100°F., revealed no sign of flutter.

The unconventional behavior of the wing in this peculiar "flag-waving" flutter presents an interesting problem in aerothermoelasticity. Much evidence exists on the harmful effect of the thermal stresses on the rigidity and the higher vibrational modes of the structure. However, the actual mechanism of the "flag-waving" flutter has not to date been completely understood. Needless to say, this type of aerothermoelastic behavior is a distinct possibility for the low aspect ratio delta-wing configuration of the hypersonic boost glide vehicle.

Curling of Leading Edge

Some other interesting forms of aerothermoelastic coupling can be conceived which involve the curling of a leading edge in hypersonic flight. The possibility of such an occurrence was pointed out by Bisplinghoff[6] using the simple model shown in Fig. 9. It is well known that at an angle of attack the aerodynamic heating rate is greater on the lower side of a wing than on the upper surface, the difference increasing with increasing angle of attack. Since the higher heating rates on the lower side cause the bottom temperatures to be greater than those on the upper surface, larger thermal expansion of the lower surface will tend to curl the leading edge up as shown in the figure. This further increases the angle of attack, and the process can continue. If the Mach Number is near the divergence condition, it is possible that the curling-up due to the thermal expansion will induce aerodynamic loads greater than those the structure is capable of resisting and the structure will collapse.

A leading-edge chordwise creep divergence phenomenon, analogous to creep buckling, may also be visualized for wings in hypersonic flight at high angles of attack.

Panel Flutter

The behavior of a panel supported at its ends and subjected to a high speed flow over one face has become an important aeroelastic problem in recent years.[10,11] The panel may be susceptible to strong self-sustained oscillations called panel flutter. This flutter may eventually cause failure of the panel. The phenomenon has been studied in wind tunnels and is believed to have caused failure of some of the early V-2 missiles launched in Germany.

Aerodynamic heating tends to buckle the panel since the outer surface skin is generally at higher temperatures than the internal supports and requires more thermal expansion than the cooler restraining supports can provide. Under these buckled conditions, skin panels are more likely to flutter.

The flutter problem of flat panels has been extended to include the flutter characteristics of curved panels of cylindrical, conical, and other shell shapes. These elementary shapes can be used to represent more complete fuselages and missile bodies. The thermal stresses developed in such shell structures may affect the stiffness and cause aerothermoelastic problems. This is particularly evident in the regions near fuel tanks where large temperature gradients may exist.

Ablation

In the regions close to the leading edges of hypersonic vehicles, equilibrium temperatures approach stagnation temperatures and are therefore considerably higher than those shown in Fig. 6. It may be feasible to cool these regions by allowing the structure to melt off thereby making use of the latent heat of melting or vaporization (ablation).

The ablation process will change the mass and mass distribution of the structure. If the leading edge is heavy, its ablation can have an effect on the flutter properties of the wing through (1) shifting the c.g. aft, which is generally harmful, and (2) increasing the wing torsional frequency, which is generally beneficial.

Since the two effects are opposing, no a priori conclusion can be reached as to the effect of ablation on the flutter properties of a structure. Each particular design must be analyzed on an *ad hoc* basis to ascertain the effects of ablation on the aerothermoelastic properties of the airframe.

Another facet of this problem is consideration of the aerothermoelastic integrity of the airframe when more extensive sections of structural skin are allowed to abate, such as might be the case for a one-shot vehicle.

A new intriguing scientific problem, and perhaps an important aerothermoelastic problem for sustained-flight hypersonic vehicles, can be deduced from meteorological and aerophysical considerations. At the flight

speeds envisioned for the boost-glide vehicle, the energy of the molecules of the impinging air could exceed the binding energy of the surface material molecular lattice. Metal ions might therefore be sputtered off, giving rise to what is, in effect, an ablation of the surface through erosion, particularly of the leading edges. It is not at all unlikely that these metal ions, in moving downstream, would combine with oxygen in the air, releasing heat during the process, much in the same way that the meteor trail is formed. This heat would be released locally and perhaps randomly downstream of the "erosion point." These local hot spots could, therefore, occur in regions over the downstream portions of the lifting and control surfaces, which extend outward from the centerline into the airstream. This could give rise to uneven, excessive, localized heating of the skin by exposure to local equilibrium temperatures which are much greater than the steady-state equilibrium temperatures calculated for the flight. This localized uneven heating could give rise to excessive local thermal stresses, local buckling, and other structural deformations which would result in peculiar aerothermoelastic behavior of the local panel or surface.

Control Surface Effectiveness and Rigidity

The effectiveness of aileron, rudder, and elevator controls is strongly dependent on the elastic stiffness of the structure and constitutes a well-known static aeroelastic problem. Generally, structural deflections tend to reduce the control effectiveness and have even been known to cause control reversals and static instabilities in flight. Aerodynamic heating may cause reductions in the structural stiffness because of thermal stresses and reduction in the modulus of elasticity, thereby causing additional loss of maneuvering capability of the vehicle. The effect of heating is similar in principle to that described previously with regard to the loss of torsional stiffness of the wing and can be analyzed in a similar fashion.

In addition to the structure rigidity of the lifting surface itself, the rigidity against rotation-of-the-control-surface provided by the boost mechanism plays an important role in aeroelastic problems involving control surfaces. This introduces considerations of the impedance properties of both open- and closed-loop boost control systems which may be markedly affected by temperature. The design of boost control systems to operate adequately in high-temperature environments is an obvious problem in hypersonic vehicles.

Fuselage Aerothermoelastic Problems

In addition to lifting surface aerothermoelastic problems, there remains also the possibility that the fuselage wing-body combination as a whole will experience aeroelastic and aerothermoelastic difficulties. The highly swept delta wings and slender fuselages of boost-glide vehicles tend to make the fuselage provide an increasingly larger share of the aerodynamic lifting forces both steady and oscillatory. These air forces may give rise to unusual types of aeroelastic problem involving large fuselage deformations. The treatment of these aeroelastic problems will require viewing the wing-body combination as a whole, as is done in slender body aerodynamic theory. The addition of aerodynamic heating aggravates these aeroelastic problems.

Experimental Methods

One has only to look at the great dependence on testing in the engine field to conclude that the development of adequate high-temperature structure and structural materials by analytical means alone appears most unlikely. The methods at hand for aerothermoelastic testing leave something to be desired. New and unique structural testing facilities, as unlike the present facilities as the wind tunnel of 30 years ago is unlike the varied and sophisticated tools available to the aerodynamicist of today, will be required before substantial progress can be made.

In assessing the tests that are necessary and feasible for the development of high-temperature structures, it is apparent that complete simulation by true models operating in a truly hypersonic airstream is an extremely complex problem. With our present lack of adequate scaling and similarity laws, this complete simulation can be achieved only by models which approach the prototype in size. Even with the development of adequate scaling and similarity laws, completely simultaneous simulation of all modes of aerothermoelastic behavior may be impossible to obtain in the laboratory since scaling of certain similarity requirements may conflict—e.g., the simultaneous provision of Mach Number and Reynolds Number. It may, therefore, be necessary to accept carefully considered compromises by relaxing one or more of the requirements while obtaining full simulation of the other variables.

Thus it may be necessary to continue to think in terms of a number of "restricted purpose" models rather than one all-purpose model. As is the practice today, each model would be designed for the investigation of a particular phenomenon, one that must be recognized in advance. Each model would generally be tested in a different type of facility. Three model types can be envisioned: (1) models which are designed for the study of the heat transfer from the boundary layer to the structure; (2) models which are designed for the study of structural behavior in high-temperature environments; and (3) models which are designed for the study of aeroelastic, or certain restricted forms of aerothermoelastic, behavior.

The heat input to a structure is a basic ingredient of thermoelastic and aerothermoelastic design and theory. The primary heat input to a structure, in flight, occurs through the transfer of heat between the airstream and the vehicle in motion. A continuous flow wind tunnel, operating at the proper Mach Number, is an ideal facility for studies of heat-transfer models. When account is taken of the interacting heat transfer between the boundary layer and the body, six nondimen-

sional similarity conditions must be satisfied in order to achieve complete similarity between a prototype and its corresponding wind-tunnel model for the case of laminar flow.[12] Complete similarity is generally not feasible. Various degrees of approximation may be obtained by adjusting the four variables of wind-tunnel pressure and temperature and model length and material.

The task of providing facilities for structural model, component, and assembly tests for hypersonic vehicles may well prove to be one of the most formidable laboratory equipment problems yet faced by aeronautical engineers. Three problems must be overcome. The *first* is that of delivering the required heat input to the surface of the structure. The *second* is the application of the required load input at the same time that the heat input is applied. The *third* is that of measuring the response of the structure.

Of the various methods that can be devised for producing heat inputs, few satisfy all the special conditions that must be imposed on a practical laboratory system. One of the severest limitations on the laboratory system is the requirement for programing the time history of thermal input to the model. Elaborate electronic control devices are required in addition to low inertia heat input elements.

Since, at the present time, the radiant heater provides a convenient solution to the problem of thermal input, radiant heating facilities have become important tools in studying the effects of heating on the stiffness and vibration frequencies of structures resulting from thermal stresses and deterioration of the material modulus of elasticity. However, the power requirements for heat input simulation may get out of hand when simulation for hypersonic flights using reasonably sized models is attempted. In estimating the power requirements of radiant heating facilities, an appreciation can first be obtained of the effectiveness of a hypersonic airplane as a generator of heat. For example, for the boost-glide vehicle trajectory described in Figs. 5 and 6, a peak thermal density of approximately 100 kw. per sq.ft. is reached. Taking account of average radiation losses and assuming a coated skin with an absorptivity of 0.8, electric power of 260 kw. per sq.ft. must be delivered to a radiant heating facility. The power density required for laboratory tests of these hypersonic vehicles is so great as to be beyond the capabilities of presently available radiant heating elements.

A great deal of ingenuity is required to devise schemes of applying flight loads and heat input simultaneously in structural test facilities. Since strain rate is an important parameter in elevated temperature testing, it will be necessary for loading devices to simulate rates of loading, as well as peak intensity.

Measurement of structural response involves the parameters of temperature and strain. The thermocouple principle provides a means of reliably measuring temperatures over a wide range. However, the electrical resistance strain gage, so widely used in room temperature experimental stress analysis, may fall by the wayside in highly elevated temperature environments, even with recent improvements for "high-temperature" applications. New developments in strain and stress measuring techniques may be required before high-temperature strains can be correctly and reliably measured.

Testing "restricted purpose" aeroelastic models, used in particular for flutter models, has heretofore been an indispensable aid in designing structures to avoid harmful aeroelastic phenomena. There have been two basically different approaches to the use of such models. In one, the model tests are designed to obtain coefficients to be inserted into the theory. In the other, the model test is designed as an analog of the full-scale problem.[6]

A supersonic blowdown tunnel is an example of a laboratory facility for flutter research and development testing at supersonic Mach Numbers. For hypersonic testing it will be necessary to heat the supply air in order to conduct aerothermoelastic tests. During an experiment conducted in a heated supply air wind tunnel on a multiweb wing, Dryden and Duberg[7] reported that NACA had encountered the chordwise "flag-waving" type of flutter mentioned previously. Such a flutter mode had heretofore been virtually unknown in practical flutter testing. A true flutter model simulating all the elastic, inertial, unsteady aerodynamics and heat-transfer properties of a prototype is virtually out of the question, except for geometric scale ratios of nearly one. It thus becomes apparent again that "restricted purpose" models must be employed. In addition to employing heated air in wind-tunnel experiments, it may also be possible to test aeroelastic models in tunnels with unheated air by artificially incorporating the stiffness losses produced by aerodynamic heating. This can, in principle, be accomplished by building the stiffness which exists at one or more points along a mission profile—as calculated or as determined by testing a scaled structural model in a heating device—into a series of room-temperature flutter models, which can then be inserted into an air stream whose Mach Number corresponds to the model stiffness. However, if the temperature environment of the prototype is such that there are important and sudden variations in the elastic constants with temperature and time, use of the same material in model and prototype is mandatory. This may impose a practical testing difficulty in attempting to use "reduced-stiffness" room-temperature models for aerothermoelastic testing.

Rockets provide a means of aerothermoelastic testing under more realistic combinations of Mach Number and stagnation temperature than the usual, even if heated, wind tunnel, particularly at the high Mach Numbers. However, the cost, the overall relative uncertainty of the test environment, and the restrictive size of the structural samples that can be used economically preclude their wide acceptance as a primary general aerothermoelastic tool.

With the advent of high-speed track facilities, the rocket sled has begun to take its place in the arsenal of aeroelastic and aerothermoelastic experimental techniques. With the use of rocket sleds operating at or near sea-level conditions, it is possible to evaluate the aeroelastic and some of the aerothermoelastic characteristics of a full-scale article, such as a wing, tail, etc., under conditions of high dynamic pressure and relatively high heating rates. In many cases, a major portion of the actual aircraft structure may be used to realize the desired degree of simulation. However, the cost and complexity of extending the performance of rocket sleds beyond somewhere near a Mach Number of 5, as well as the short time of an experiment, places a natural limit on the utility of this technique for aerothermoelastic research.

Research aircraft offer still another invaluable method of aerothermoelastic research. The research aircraft, properly conceived and executed, is the one tool available to the research scientist and engineer that can provide full simulation of all the parameters of importance simultaneously. Its role in research is to explore the gray area between where one *knows* what is possible and where one *knows* it is impossible to do anything. As is done with a wind tunnel, a radiant heating facility, or other research tools, its justification and support should derive from its scientific utility, which in turn arises both from its ability to permit investigation of the important parameters of a problem under full-scale operational conditions and from its utility in calling attention to problems that may not have emerged from the best deductive reasoning made with the knowledge available at the time. Such a vehicle could be of particular importance in the proper assessment of the strength of the feedback couplings between kinetic or aerodynamic heating and the elastic, inertial, and aerodynamic forces in aerothermoelastic phenomena.

Before leaving the subject of facilities, mention must be made of the greatest single facility in research—the ingenuity and knowledge of the human scientist and engineer. Much of the design for high-temperature structures will revolve around clever methods for avoiding thermal stressing while still providing the efficient structural form which is the modern airplane.

Conclusions

This paper has attempted to give a broad view of what can become, in the future, a major problem in airframe design—aerothermoelasticity. The problem is already with us, and, as we penetrate further into the thermal thicket, the problem will assume an ever-increasing importance. It is more than likely that, in the same way that aeroelastic considerations have begun to dominate supersonic airplane design, aerothermoelastic considerations may be a controlling factor in the design of hypersonic airframes.

The problem areas delineated in this paper are not meant to be exhaustive but rather were presented to illustrate some of the more important aspects of aerothermoelastic phenomena.

The present method of handling aerothermoelastic problems is to divide the general problem into two separate problems—the aerothermal and the aeroelastic—each of which can be handled, to a large degree, by methods already available to the structural engineer. This division rests on assumptions which may not always be valid under high-temperature flight environments. Research is needed to clarify the strength of the interactions between heat input and aeroelastic phenomena, other than the well-known reductions in moduli of elasticity of the structural materials and the introduction of thermal stresses.

The general problem of aerothermoelasticity is too complex to be successfully approached by analytical means alone. New and unique experimental facilities are needed for aerothermoelastic research before significant progress can be made. Model tests are useful in developing optimum theories. Complete simulation in the laboratory of all the elastic, inertial, and unsteady aerodynamics and of heat-transfer properties of a prototype is virtually out of the question, except for geometric scale ratios of nearly one. Thus, "restricted purpose" models must be employed.

The richness of the field of aerothermoelasticity, as an almost completely unexplored field of research, offers tempting problems to people of all talents and inclinations. In designing tomorrow's hypersonic airplanes and missiles, the clearly defined boundaries of structural analysis, thermodynamics, and aerodynamics merge, creating a new specialization—aerothermoelasticity.

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(*Continued on page 64*)

This paper deals with some of the three-dimensional aspects of orbits in close vicinity to the planet—i.e., orbits of arrival and departure—studied from the standpoint of flight economy.

It is assumed that we are dealing with high thrust accelerations such as would be obtained from chemical propulsion.

One special case of arrival, the return to earth, is briefly considered.

Departure and Return in Interplanetary Flight

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THE TECHNIQUE for most efficient interplanetary flight is well known. At departure from planet P_1 (Fig. 1), the vehicle possesses the orbital velocity V_1 of the planet. An incremental velocity ΔV_1 is added which causes the vehicle to travel along the Kepler ellipse $P_1 P_2$, generally referred to as the transfer orbit. When arriving at planet P_2 the vehicle velocity is again increased by an increment ΔV_2, which brings its speed up to the orbital velocity V_2 of planet P_2.

For best efficiency, the transfer orbit P_1P_2 should be tangent to both planet orbits 1 and 2. This is possible only when both planet orbits are in the same plane; this therefore will never be an actual case. It is easy to show that the transfer orbit cannot be tangent to the planet orbits when the latter are not coplanar. If we project all orbits on a heliocentric sphere (Fig. 2), their projec-

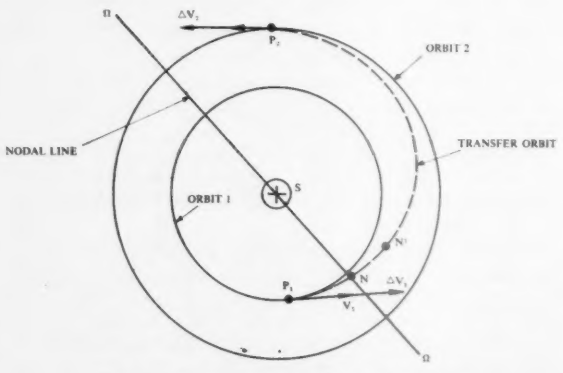

FIG. 1. Interplanetary orbits—plan view.

SYMBOLS

V	=	velocity
V_c	=	circular velocity *at perigee**
V_∞	=	hyperbolic excess velocity
V_s	=	surface velocity on the planet due to its diurnal rotation
ΔV	=	velocity impulse
ΔV_{ch}	=	transfer impulse, circle to hyperbola
ΔV_{eh}	=	transfer impulse, ellipse to hyperbola
r	=	distance, ship to center of planet
R_A	=	ratio between apogee* and perigee distances
ϵ	=	angle between planetary and interplanetary orbits
θ	=	angle between hyperbolic excess velocity and orbital velocity of planet
τ	=	latitude of target direction
λ	=	latitude of launching site
ι	=	inclination of target direction to initial orbital plane
α	=	angle between orbital planes
ϕ	=	angle between major axis of ellipse and asymptote of hyperbola in an ellipse-hyperbola transfer
ω	=	diurnal rotational velocity of planet

Subscripts

P	=	perigee
A	=	apogee
A	=	apsidal
e	=	ellipse
h	=	hyperbola
p	=	parabola

* The terms *apogee* and *perigee* have been used as applying to orbits around any planet, even though, strictly speaking, they should apply only to earth-centered orbits.

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Mr. Bossart is Technical Director.

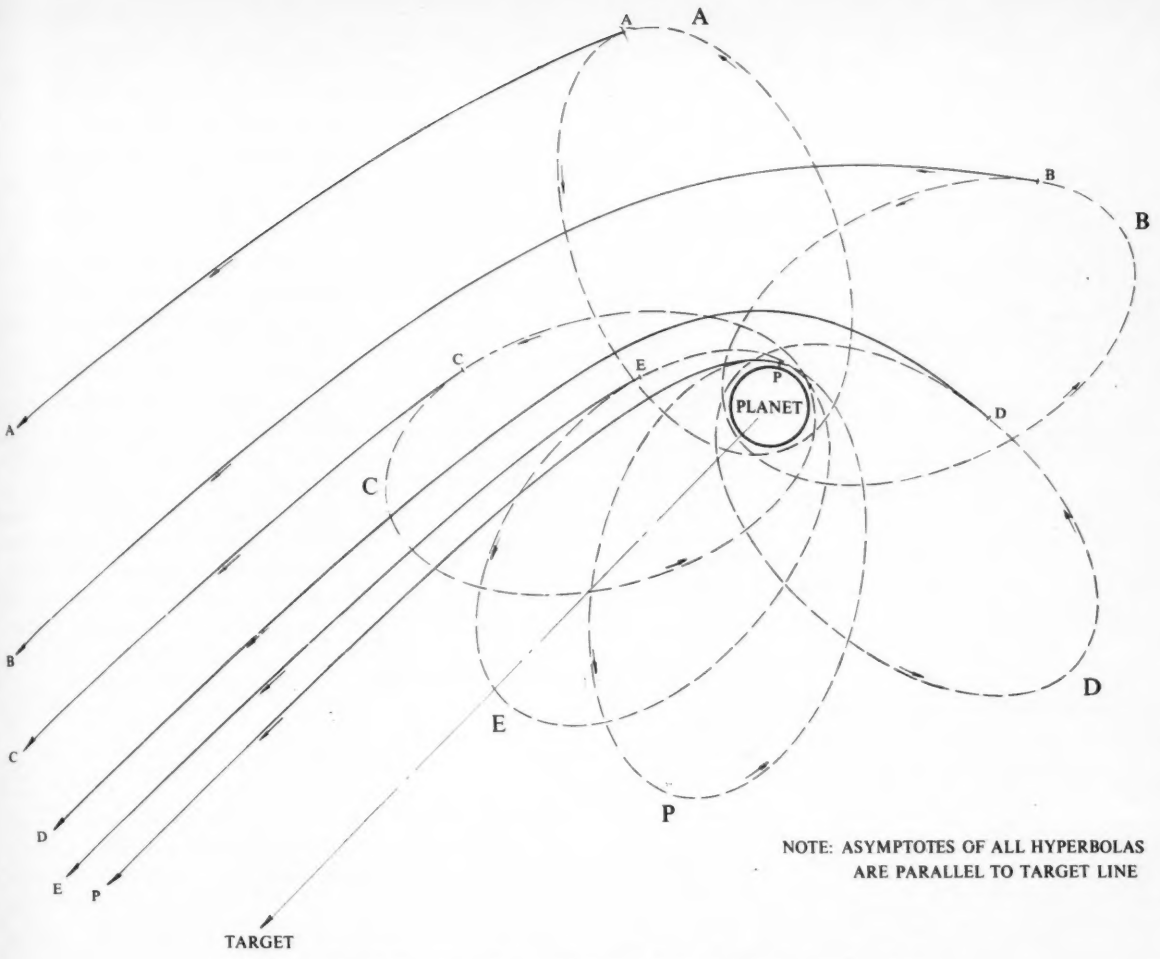

FIG. 6. Hyperbolic escape into a given target direction from elliptic orbit.

tions must be great circles since, according to Kepler's law, each orbit is located in a plane containing the sun. Two orbits cannot be tangent to one another since on a sphere two great circles cannot be tangent.

From Fig. 2 it can also be seen that, if tangency is to be achieved, the transfer orbit has to consist of two parts—P_1N, located in the plane of orbit 1, and $N\,P_2$, located in the plane of orbit 2. This requires that an impulse ΔV_N be applied at the nodal point N.

It can be shown that a more efficient transfer can be effected along the planes P_1N' and $N'P_2$. It is not the object of this paper to determine the optimum location of point N'. Suffice it to observe that, in general, the transfer orbits meet the planet orbits at angles ϵ_1 and ϵ_2. This means that the velocity increments ΔV_1 and ΔV_2 will have components perpendicular to the planet velocities V_1 and V_2.

The incremental velocities ΔV_1 and ΔV_2 are the velocities of the vehicle with respect to the planets P_1 and P_2, respectively. They are, of course, the so-called hyperbolic excess velocities attained at large distances from the planet ("large distances" meaning several tens of planet radii, which are still small distances in terms of planetary orbit dimensions, the latter being measured in tens of thousands of planet radii). ΔV_1 and ΔV_2 are directed along asymptotes of the hyperbolas of escape from the planets.

Rules for Optimization

The basic process in interplanetary flight is to overcome gravitational potential energy by means of kinetic energy.

The capability of a rocket vehicle is measured by its ability to build up translational momentum per unit mass, in the absence of drag and gravitation. (This total momentum per unit mass is sometimes called ideal velocity—V_{id}.)

A good flight path, then, is one that uses the available momentum to best advantage to achieve the highest possible kinetic energy per unit mass.

To this end the following rules should be observed:

(1) Avoid applying thrust in a direction normal to the flight path. This means that the trajectory should

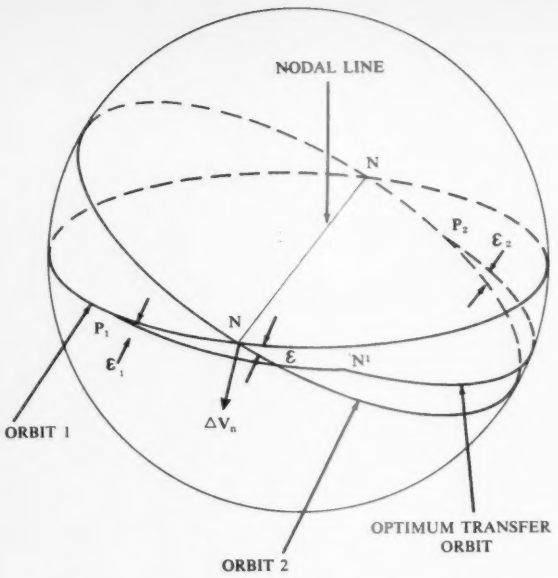

FIG. 2. Interplanetary orbits in three dimensions.

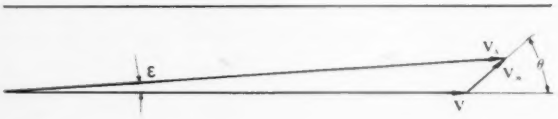

FIG. 3. Direction of velocity increment for departure.

be planned in such a way that changes in direction other than those caused by gravity are not required.

(2) If such changes in direction are unavoidable (such as in the case of ΔV_N mentioned above), they should be made when the velocity is lowest. In the case of an elliptic orbit, for instance, they should be made at apogee rather than perigee.

The change in kinetic energy accrued from a given increment of momentum will be larger when the velocity of the rocket is high than when it is low. This is evident from the relationship

$$\Delta\text{kin.en.} = [(V + \Delta V)^2/2] - (V^2/2) = V\Delta V + (\Delta V^2/2)$$

From this we derive two more rules:

(3) Whenever possible, apply thrust in those parts of the trajectory where the velocity is highest—e.g., in the perigee of an elliptic orbit rather than in the apogee.

(4) In powered flight try to build up kinetic energy in preference to potential energy. In other words, avoid fighting gravity with thrust.

In many applications these rules will be found to be conflicting. In such cases, optimization is arrived at through compromise.

TARGET DIRECTION

At departure from the vicinity of a planet the ship is approximately at an apside of the transfer ellipse. It therefore has apsidal velocity V_A. As a general rule the vector V_A will make an angle ϵ with the orbit velocity V of the planet (Fig. 3). In general, ϵ will be made up *in toto* or for the largest part from the angle ϵ_1 (Fig. 2) between the two orbital planes. The difference $\vec{V}_\infty$ between the vectors $\vec{V}$ and $\vec{V}_A$ is the "hyperbolic excess" or escape velocity from the planet. The direction of $\vec{V}_\infty$ is the direction of the asymptote of the hyperbola of escape and will be called the target direction.

Since V_∞ is always small compared to V, the angle θ of the target direction can be appreciable even though ϵ is extremely small. For instance, when leaving Venus for the Earth, V = 115,000 ft./sec., and V_A = 124,000 ft./sec. Then, if we assume $\epsilon = 1.7°$—i.e., half of the angle between the two planet orbits—we get $\theta = 22.4°$.

The inclination of the equator of Venus to its orbital plane is unknown. But assuming that it is about the same as that of the earth (23.5°), then, when firing at solstice, the target direction could be inclined to the equator as much as 23.5 + 22.4 = 45.9°. This may have an important bearing on the economy of the departure maneuver from a "waiting orbit," as will be seen later. It means that, because of precession occurring during the waiting period, the waiting orbit can be at right angles to the target direction.

ORBITS OF ARRIVAL AND DEPARTURE

Contrary to what is the case with the heliocentric orbits discussed so far, an orbit of arrival or departure is centered around the planet and is governed entirely by the planet's gravitational field. Such orbits include not only the hyperbolic orbits of capture and escape but also closed orbits—circular or elliptic—surrounding the planet.

The closed orbits are often thought of as orbits of convenience, intended for such purposes as awaiting departure, assembling space ships, storing supplies, etc. Actually — as will be shown—these orbits are a

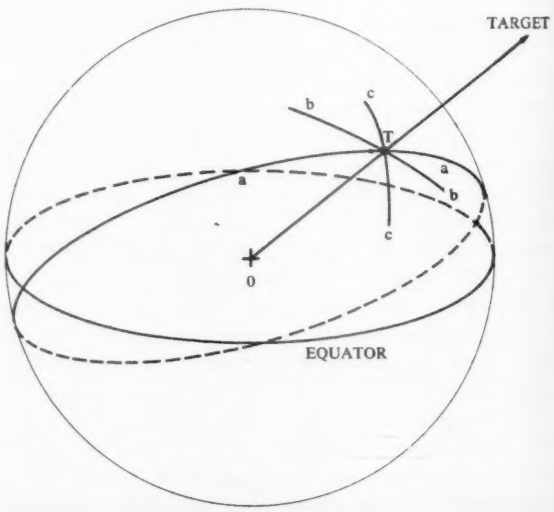

FIG. 4. Orbital planes for capture or escape.

necessity since it is only the rarest coincidence that the desired hyperbola can be entered directly from a surface launch.

The plane of an orbit of arrival or departure obviously must contain the center of the planet. Furthermore, the plane of a hyperbolic orbit of capture or escape must be parallel to the target direction. Let us project the orbit geometry on a sphere concentric with the planet (Fig. 4). Let T be the point where the radius vector parallel to the target direction pierces the sphere. Orbital planes whose traces a-a, b-b, and c-c pass through T are all satisfactory.

When we pass now from the hyperbolic orbit to a closed orbit—or vice versa—it will be most economical to have both orbits coplanar.* In this way, no energy-wasting change in direction will be required. Again, all planes passing through OT will be satisfactory.

However, if we wish to land on the planet or establish a closed orbit from a surface launch, then it can be shown that the greatest benefit is derived from the diurnal rotation of the planet by choosing the orbit plane a-a which has the lowest inclination to the planet's equator. This inclination τ is equal to the latitude of the target point T.

It is taken for granted that the direction of rotation of the orbit will be that of the planet.

Departure From Surface Launch

The best closed orbit of departure is a circular orbit of the smallest practical radius—the smallest practical radius meaning the lowest altitude compatible with the planet's surface topography or atmospheric density. The reason for this obviously is to comply with optimization rules number 3 and 4: the impulse required to transfer from the closed orbit to the hyperbolic should be applied at the highest possible (circular) velocity.

The orbital plane should pass through the target direction T (Fig. 5) and for best economy should have an inclination to the equator equal to the latitude τ of point T. This means that the launching should be timed to the instant that the launching site L passes through the orbital plane. Let A be the point where this occurs and B the intersection of the orbit with the equator. If we now draw the meridian AC, the spherical triangle ABC will have the following properties:

Angle B $= \tau =$ inclination of the orbit to the equator
Angle C $= 90°$
Arc AC $= \lambda =$ latitude of the launching site

Solving for angle BAC we find $\sin \text{BAC} = \cos \tau \div \cos \lambda$. The velocity of the launching site due to the rotation of the planet is $V_s = r\omega \cos \lambda$, where r is the radius of the planet and ω its angular velocity.

The contribution of V_s to the desired circular orbit velocity V_c is $V_s \cos \widehat{V_s V_c}$. If we now observe that the angle $\widehat{V_s V_c}$ is complimentary to angle BAC, we can write that this contribution is

$$V_s \sin \text{BAC} = r\,\omega \cos \lambda \cdot (\cos \tau / \cos \lambda) = r\,\omega \cos \tau$$

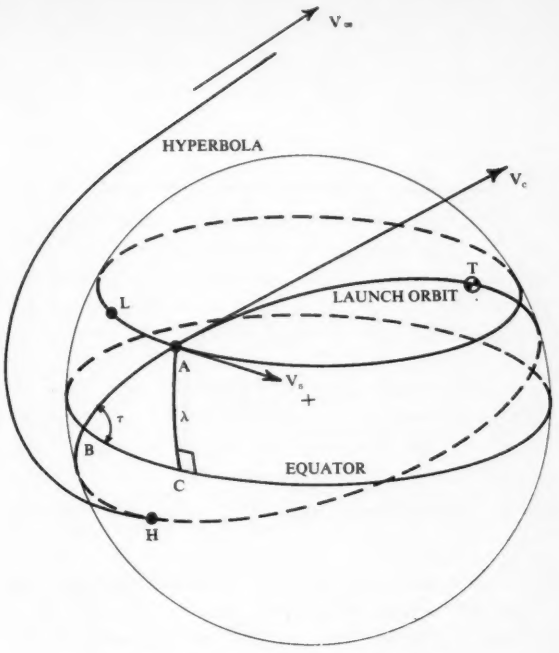

FIG. 5. Departure from surface launch.

We therefore arrive at the interesting conclusion that:

(1) The benefit derived from the planet's rotation is largest when the inclination of the orbit is a minimum—i.e., when it is *equal to either the latitude of the target direction* (as in Fig. 5) *or the latitude of the launching site, whichever is larger.*

(2) When the latitude of the launching site is equal to or less than the latitude of the target direction, *this benefit is independent of the launching site location.*

We can also conclude that, even though the location of the launching site for any particular mission does not matter as long as its latitude does not exceed that of the target, nevertheless the most favorable location for *all missions* is at the equator.

This is particularly important if we remember that the target latitude varies with the seasons of the year. If we intend to fire in the plane of the ecliptic, for instance, the target latitude will be $\pm 23\frac{1}{2}°$ at solstice and 0° at equinox.

Having entered the closed departure orbit in A, we leave it in H to go into the escape hyperbola. The final velocity impulse given in H is

$$\Delta V_{ch} = \sqrt{2V_c^2 + V_\infty^2} - V_c \qquad (1)$$

where V_c is the velocity in the circular orbit and V_∞ the required hyperbolic excess velocity.

The above expression assumes a cotangential trans-

* Only in the case of departure from a long-established closed orbit—such as a so-called waiting orbit—is this not always feasible.

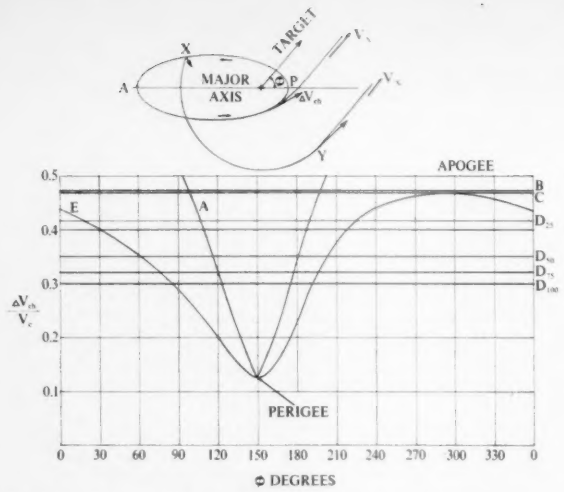

FIG. 7. Transfer impulse from ellipse to hyperbola—coplanar.

fer which is the most efficient. It follows that H is the perigee of the hyperbola, and therefore the arc HT is the angle between the asymptote and the major axis. This angle is

$$\phi = \text{arc tan } [(V_\infty/V_c)\sqrt{(V_\infty/V_c)^2 + 2}] \qquad (2)$$

We see that H is located at a definite longitude in the closed orbit, and it now becomes clear that

(1) The closed orbit is a necessity and—as stated before—not merely a convenience. We must reach the point H before we can transfer to the escape orbit.

(2) The closed orbit should be a circle and not an ellipse since in an ellipse the velocity at point H would be less than circular and the acquisition of escape energy therefore would be less efficient.

Departure From Elliptic Orbit—Coplanar

Transfer from an elliptic closed orbit to a hyperbola is nevertheless at times a necessary maneuver. Fig. 6* indicates how the transfer point wanders away from the perigee P when the angle between the major axis and the target direction deviates from the optimum. Transfer has been assumed to be cotangential in order to comply with optimization rule number one.

The penalty incurred in terms of increased velocity impulse required for transfer from a point other than perigee is shown in Fig. 7 for a typical example. In this example the ellipse was assumed to have an eccentricity of 0.8, which results in an apogee distance of nine times the perigee distance. It was further assumed that the hyperbolic excess velocity was 40 per cent of the circular velocity at perigee: $V_\infty = 0.4V_c$. This is roughly the magnitude required for travel between Venus, earth, and Mars when the perigee is taken as close to the planet surface as practical (same as in the circular orbit case).

For these particular numerical proportions, the velocities in the ellipse and hyperbola are given by

$$V_e = V_c\sqrt{(2r_P/r) - 0.20}$$

$$V_h = V_c\sqrt{(2r_P/r) + 0.16}$$

where r is the distance to the center of the planet and r_P the perigee distance.

The difference is the velocity impulse required for transfer

$$\Delta V_{eh}/V_c = \sqrt{(2r_P/r) + 0.16} - \sqrt{(2r_P/r) - 0.20} \qquad (3)$$

This ratio is plotted in Fig. 7 against the angle ϕ between target direction and major axis (the latter was obtained graphically).

The minimum and maximum occur at perigee and apogee. Substituting r_p and $r_A = 9r_p$ for r in Eq. (3) yields

$$(\Delta V_{eh})_P = 0.128\ V_c$$

$$(\Delta V_{eh})_A = 0.469\ V_c$$

The question may be raised whether it is justifiable to restrict the investigation to the case of cotangential transfer only. The analytical optimization of non-cotangential transfers is extremely involved and does not look promising as to improved results. It was therefore not attempted. The following alternate methods were investigated. All but Method D—which incidentally is cotangential—were found to be inferior.

Method A

The required hyperbolic velocity is imparted at the most efficient point of the ellipse—namely, perigee. The resulting asymptotic flight direction makes an angle ϕ_P with the major axis. In the example of Fig. 7, $\phi_P = 150°$. At a "very large" distance from the planet the velocity vector V_∞ is rotated into the desired angle ϕ_P. This requires an additional velocity impulse of $\Delta V = 2V_\infty \sin(\phi_P - \phi)/2$.

The total velocity impulse for the maneuver (assuming $V_\infty = 0.4\ V_c$) is then

$$\Delta V = \Delta V_{eh} + |2V_\infty \sin(\phi_P - \phi)/2| = [0.128 + |0.8 \sin(\phi_P - \phi)/2|]\ V_c$$

It is plotted in Fig. 7 as curve A.

Method B

Only parabolic velocity is given to the ship at perigee. At a "very large" distance, the velocity with respect to the planet becomes zero. At this point the impulse $\Delta V = V_\infty$ is given in the desired direction. The total velocity impulse for this maneuver is

$$\Delta V = (V_p)_P - (V_e)_P + V_\infty = (\sqrt{2} - 1.342 + 0.4)\ V_c = 0.472\ V_c$$

It is shown on line B in Fig. 7.

Method C

At some point X on the ellipse, impulse is applied to change the trajectory into a circle. The circle is fol-

* See page 45.

lowed up to a point Y (Fig. 7) where the final impulse to hyperbolic velocity is given. Y is chosen in such fashion that the desired direction of the asymptote is achieved. Analytical optimization was performed to find the best location of X. It was found to be at apogee. Line C in Fig. 7 shows the required total impulse.

Method D

The most efficient method was found to be a cotangential one. Like Method A it tends to divorce completely the energy-producing impulse from the impulse that produces only change in direction. It involves, however, a more complicated maneuver, inasmuch as thrust has to be applied four times.

At perigee P the velocity is increased to a value short of parabolic by a tangential impulse ΔV_1 (Fig. 8). The resulting ellipse has an apogee at A. ΔV_2 brings the velocity to circular. The ship now follows the circular arc $AA_1 = \phi_P - \phi$. At point A_1 the velocity is reduced by $\Delta V_3 = \Delta V_2$ so that the ellipse A_1P_1 is equal to ellipse AP. When perigee P_1 is reached, increment ΔV_4 will change the path into the hyperbola of the required velocity and asymptote direction ϕ.

The resulting total impulse $\Delta V_1 + \Delta V_4 + 2\Delta V_2$ obviously depends on the apogee distance OA chosen. The curves D_{25}, D_{50}, D_{75}, and D_{100} in Fig. 7 correspond to apogee distances of 25, 50, 75, and 100 times the perigee distance OP.

The quantity $\Delta V_1 + \Delta V_4 = \Delta V_{eh}$, the optimum transfer impulse from the original ellipse at perigee

$$\Delta V_2 + \Delta V_3 = 2\Delta V_2 = 2V_c\left\{\sqrt{2/[R_A\,(R_A+1)]} - \sqrt{1/R_A}\right\}$$

where V_c is circular velocity at perigee and $R_A = \text{OA} \div \text{OP}$.

The maximum gain in impulse over the direct transfer method is 0.17 V_c. This may well justify the complication of the maneuver. It is envisaged that in early interplanetary expeditions it will not be known in advance how bad an angle ϕ we will have to cope with. In this case it would be wise to plan on taking advantage of all or part of the possible 0.17 V_c gain in order to reduce the mass ratio required. We would have the assurance of being able to return from the worst condition but would not have to resort to the complicated maneuver if conditions were favorable.

In starting from a surface launch, the closed departure orbit should be a circle, as stated before. The elliptic orbit of departure comes into the picture only when the mission consists of circumnavigating a planet without landing. It offers a decided advantage over the circular orbit. Introducing the value $V_\infty = 0.4\ V_c$ into Eq. (1), we find the necessary impulse for capture into or return from a circular orbit:

$$\Delta V_{eh} = V_c\sqrt{2 + 0.16} - V_c = 0.470\ V_c$$

Table 1 compares the total impulse required for the circle and the ellipse of eccentricity 0.8:

TABLE 1

	Circle	Most Favorable Ellipse	Least Favorable Ellipse
Arrival	0.470 V_c	0.128 V_c	0.128
Departure	0.470 V_c	0.128 V_c	0.300
Total	0.940 V_c	0.256 V_c	0.428 V_c

Capture into the ellipse would be made at perigee. The least favorable case is where, at the time of departure, the major axis of the ellipse has turned in such an orientation as to compel us to resort to the complicated maneuver described above. Even then, the advantage over the circular orbit still amounts to some 1/2 V_c. This corresponds to a *reduction in size* of the vehicle required for the mission by a *factor of 2 or 3*, even for today's best chemical propellants.

Eccentricities larger than 0.8 would yield a further decrease in impulse. They would be undesirable from the observational standpoint, however, since they greatly shorten the proportion of orbital time spent in close proximity to the planet.

Departure From Precessed Circular Orbit

Hyperbolic and closed orbits of arrival will always be coplanar. We may assume that this will also be the case for orbits of departure from surface launch. Unfortunately, when we leave from a closed orbit that has been established around a planet for any length of time, the plane of this orbit probably has precessed, so that it no longer contains the target direction. If at the time of arrival the target direction is at 45° to the

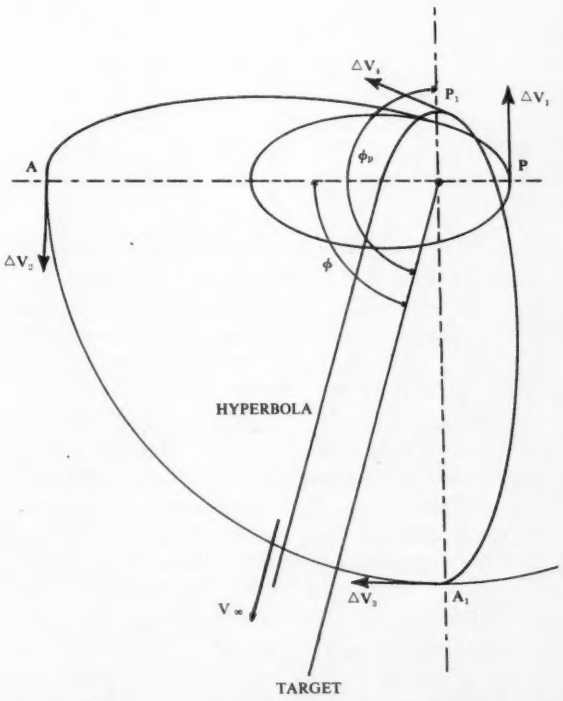

FIG. 8. Coplanar transfer from elliptic to hyperbolic orbit with rotation of perigee.

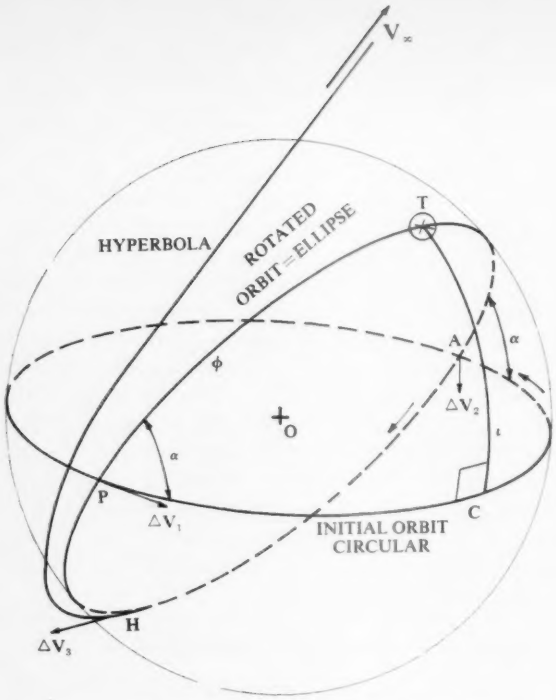

FIG. 9. Transfer from precessed circular orbit to hyperbola.

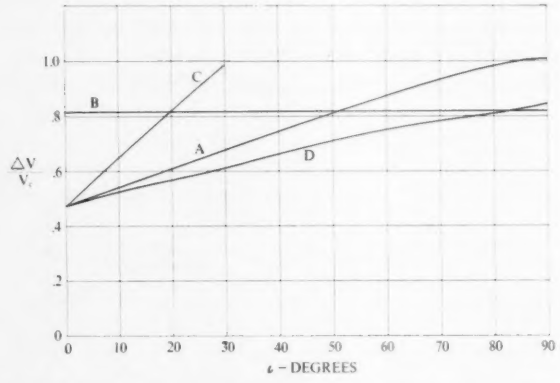

FIG. 10. Transfer impulse from precessed circle to hyperbola.

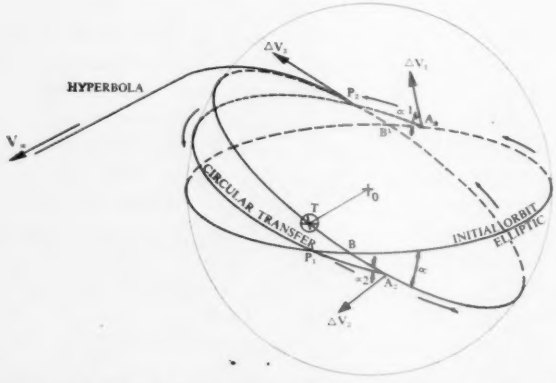

FIG. 11. Transfer from precessed elliptic orbit to hyperbola.

equator, it is possible for the orbit to precess to the extent that its plane will be at right angles to the target direction at the time of departure. It was shown earlier that this might be the case for a waiting orbit around Venus.

Various departure maneuvers are possible to cope with this situation. We shall first treat the case of the circular orbit (velocity being V_c). Fig. 9 represents a sphere concentric with the planet O on which all closed orbits have been projected as well as the target direction T. The target makes an angle ι = arc TC with the precessed orbit APC from which the departure maneuver starts.

Method A

Cotangential transfer from the circle into the hyperbola is made at a point in the orbit such that the asymptote will make the smallest possible angle with the target direction. This minimum angle is, of course, equal to ι, the angle between target T and the orbit plane APC. At a "very large" distance from the planet, the hyperbolic velocity vector V_∞ is rotated into the target direction. The total velocity impulse required for the maneuver is

$$\Delta V = \sqrt{2V_c^2 + V_\infty^2} - V_c + 2V_\infty \sin(\iota/2)$$

Adopting again for an example $V_\infty = 0.4\ V_c$, this becomes

$$\Delta V = V_c[\sqrt{2.16} - 1 + 0.8 \sin(\iota/2)]$$

This value is plotted as curve A in Fig. 10.

Method B

Cotangential transfer from the circle to a parabola. At a "very large" distance, create V_∞ from zero velocity. Total impulse is

$$\Delta V = \sqrt{2}V_c - V_c + V_\infty = V_c(\sqrt{2} - 1 + 0.4) = 0.814\ V_c$$

Line B in Fig. 10 represents this value.

Method C

Here we first rotate the circular orbit into a plane PTA containing the target direction. This will require the least impulse when the tilt angle α is at a minimum—i.e., when $\alpha = \iota$. This means that the point P, where tilting thrust is applied, is at 90° from point C. From the new circular orbit PTA, a cotangential transfer into the desired hyperbola is executed.

The total impulse for $V_\infty = 0.4 V_c$ is

$$\Delta V = 2V_c \sin(\iota/2) + \sqrt{2V_c^2 + V_\infty^2} - V_c = [\sqrt{2.16} - 1 + 2 \sin(\iota/2)]V_c$$

The result is plotted as Curve C in Fig. 10.

Method D

Again the orbital plane is rotated to contain the target direction. This time, in order to facilitate rotation, a

tangential impulse ΔV_1 is first applied at point P. This results in an elliptic orbit PCA (shown only in projection in Fig. 9). If we choose an ellipse of eccentricity 0.8, then $\Delta V_1 = 0.342\ V_c$, and the velocity at apogee is $V_A = 0.149\ V_c$. Arriving at apogee A, we apply the tilting impulse $\Delta V_2 = 2V_A \sin(\alpha/2)$, and we are now in the ellipse AHPT. At the proper point, H, the tangential impulse ΔV_3 is applied to transfer the orbit into the desired hyperbola with asymptote parallel to OT. ΔV_3 can be taken from the curve of Fig. 7.

An optimization process is required to find the best location of perigee P. When arc CP = 90°, then $\alpha = \iota$ and ΔV_2 = minimum. The angle ϕ = arc PT between the target, and the major axis is then 90°. From Fig. 7 it can be seen that this is far from the minimum condition for ΔV_3. On the other hand, when arc CP = 180°, then $\phi = 180° - \iota$ and ΔV_3 is favored, but $\alpha = 90°$ and ΔV_2 is extremely large.

From spherical trigonometry the angles ι, α, and ϕ are tied together by the relationship $\sin\phi = \sin\iota \div \sin\alpha$. From this and Fig. 7 an optimization was obtained by cross-plotting α vs. $\Delta V_3 + \Delta V_2$ for various values of ι.

The resulting total impulse $\Delta V_1 + \Delta V_2 + \Delta V_3$ is shown as curve D in Fig. 10.

It should be noted that the angle ϕ never needs to be less than 90° nor more than 180°. It will therefore not be necessary to resort to the complicated maneuver of Fig. 8.

Method D is the most efficient for target inclinations up to 80°. It is interesting to note that in the worst case of precession, where the target is at right angles to the orbit, Method B (the "parabola method") is best. Therefore, the highest that the required total velocity impulse can be is $\Delta V = 0.814\ V_c$.

Departure From Precessed Elliptic Orbit

The orbit eccentricity is again taken as 0.8 and $V_\infty = 0.4\ V_c$. The apogee and perigee velocities of such an ellipse are $V_A = 0.149\ V_c$ and $V_P = 1.342\ V_c$.

Method A can be dismissed as inefficient. Method B—the parabolic method—yields

$$\Delta V = \sqrt{2}V_c - V_P + V_\infty = V_c(\sqrt{2} - 1.342 + 0.4) = 0.472V_c$$

Methods C and D of the circular case combine into one. Fig. 11 shows the orbits projected on a sphere. The case is different from that of Fig. 9 in that we are no longer free to make the choice of the apsides of the elliptical orbit. The apogee A_1 is given to us. Therefore, rotating of the original orbit plane $A_1BB'C$ into the plane P_2BTA_2B' containing the target need not necessarily be done at apogee. Optimization has to be done not only for various values of the inclination ι but for various perigee locations for each value of ι.

Method E

For extremely unfavorable locations of the target with respect to the perigee, the following maneuver (somewhat similar to that described in Fig. 8) can be used to good advantage.

At apogee A_1 of the original ellipse an impulse ΔV_1 is applied. This not only rotates the orbit but gives it circular velocity. We proceed from A_1 to A_2 along a circular orbit. Point A_2 is chosen at the favorable distance $180° - \phi_P$ from point T, at the same time attempting to minimize angles α_1 and α_2. At A_2 impulse ΔV_2 rotates the orbit into the plane TA_2P_2 and, at the same time, gives the ship apogee velocity. The ellipse $A_2B'P_2$ is now followed to perigee P_2 where impulse ΔV_3 establishes hyperbolic transfer.

Optimization of methods D and E is beyond the scope of this paper. However, we know that the total velocity impulse for departing from a precessed elliptic orbit at worst cannot be larger than $\Delta V = 0.472\ V_c$, the latter value being that for the "parabolic method."

We can now again compare the circular and elliptic orbits for circumnavigation without landing (Table 2).

Table 2

	Most Favorable Circle	Most Favorable Ellipse	Least Favorable Circle	Least Favorable Ellipse
Arrival	0.470 V_c	0.128 V_c	0.470 V_c	0.128 V_c
Departure	0.470 V_c	0.128 V_c	0.814 V_c	0.472 V_c
Total	0.940 V_c	0.256 V_c	1.284 V_c	0.600 V_c

The two least favorable cases are the ones that must be compared since the worst condition is one for which an expedition has to be prepared. The difference in impulse is $0.684\ V_c$, which is even larger than for the case of coplanar departures.

It should be noted that the elliptic waiting orbits are acceptable only when no landing is contemplated. In case of a landing, the fuel and cargo required for the return trip still should be stored in a satellite orbit. This orbit, however, must be circular since it will require less energy to rejoin it from the return trip surface launch. The amount of fuel that has to be landed and taken-off again will thus be minimized.

Return to Earth

The return to earth is an exception to this since no subsequent take-off is contemplated. Here capture from the return hyperbola at perigee requires a velocity impulse $\Delta V_{hc} = 0.470\ V_c$ for a circular orbit as against only $\Delta V_{he} = 0.128\ V_c$ for capture into an ellipse of eccentricity 0.8.

The difference, $0.342\ V_c$, amounts to some 9,000 ft./sec. which, even with the best available chemical propellants, corresponds to better than halving the required weight. We do not halve just the weight of the return configuration, but indeed all weights involved in the entire expedition are halved.

The elongated capture ellipse will probably be used only for planning purposes. That is, we have to plan, when the expedition leaves the earth, on having sufficient fuel aboard to be able to cope with the most unfavorable situations we may encounter during the

trip and still have enough left over upon return to effect capture into the ellipse. In all probability in the actual trip we will not encounter conditions which are uniformly adverse. Reserve fuel will, therefore, be available upon return which can be used to reduce the eccentricity of the ellipse or even to make it a circle.

The concluding maneuver of the interplanetary trip is to get the payload out of the capture orbit and back to earth. The most efficient way of doing this is to transfer to a ferry vehicle launched from the earth's surface after the capture orbit has been established. The ferry vehicle will be specifically designed and instrumented for this specialized mission. Its returning stage must have a configuration capable of atmospheric re-entry.

The objection can now be made that a ferry vehicle capable of intercepting a ship in an elliptic capture orbit has twice the weight of that required for circular capture. This is true, but doubling the weight of the ferry is cheap compared to doubling the weight of the entire interplanetary expedition.

Two alternate methods for terminating the return trip have at times been suggested. Both of them are deemed inferior.

(1) The spaceship returns to a "way station" satellite permanently established in a circular orbit. By this process, not only would we lose the advantage of the elliptic capture, but the permanent orbit would almost certainly have precessed away from the direction of the arriving spaceship. Instead of the elliptic capture impulse of 0.128 V_e, the capture into a precessed circle may cost as much as 0.841 V_e. The difference—0.713 V_e or approximately 18,000 ft./sec.—would multiply the starting weight of the expedition by a factor of 4.

If a permanent station happened to be already in existence, if its precession angle happened to be small at the time of arrival of the spaceship, and if it still had sufficient reserve fuel, this maneuver would probably be preferred over launching a special intercept ferry. But most certainly the expedition should not be planned from the outset with return to a way station in mind.

(2) Atmospheric braking is often recommended as a great energy-saver. Unfortunately this method involves carrying a re-entry vehicle for the entire interplanetary trip.

A rough estimate indicates that the additional weight of a re-entry glider would increase the launching weight at the start of the expedition by an amount equal to several times the capture ferry vehicle that is eliminated in the process.

Furthermore, if atmospheric braking is to start from hyperbolic or high elliptic velocities, this maneuver would require extremely precise trajectory control. An error in altitude on arrival of as little as 10,000 ft. could easily destroy the vehicle by aerodynamic heating or kill the crew by excessive deceleration.

If to relax this situation we restrict air braking to near-circular velocities, the enormous weight advantage of elliptic capture is lost.

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This paper presents a refinement in the structural analysis dictated by the flutter requirements.

Loss of Torsional Stiffness Under Load

Lloyd E. Hackman
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THE NECESSITY for developing the method discussed in this paper evolved from obvious inaccuracies of the flutter analyses when applied to certain structures. Flutter analyses to the present time have assumed no change in torsional stiffness, or that change was negligible. When unexplainable inaccuracies presented themselves, static tests were performed to investigate possible changes of torsional stiffness under load. From the static test data it was evident that losses of GJ did occur under load. A paralleling effort to derive an analytical method for predicting loss of GJ was also initiated. The derivation of this method is described in detail in this paper. A comparison of test results with analytical predictions is made and shows satisfactory agreement within the accuracy of the tests performed.

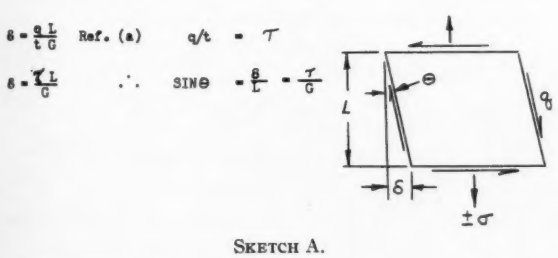
Buckling Losses

The first step in the analytical solution was to investigate an unbuckled shear panel under combined shear and direct stress. In the analysis of the panel deflected under shear, it is possible to show an increase of shear stiffness under tension and a decrease in shear stiffness under compression as shown in Sketch A.

The shear component of $\pm\sigma$ is:

$$\pm\sigma(\tau/G) = \pm\Delta\tau \quad \therefore \tau_{\text{total}} = \tau \pm \Delta\tau$$

$$\delta_{\text{total}} = [(\tau \pm \Delta\tau)L]/G, \quad \text{or } \delta_{\text{total}} = \delta \pm \Delta\delta$$



SKETCH A.

Mr. Hackman is a Senior Structures Engineer in the Structural Development Group, Columbus Division.

Symbols

A_{ve} = effective stringer area, in.
A = stringer area, in.^{2}
a = panel length, in.
b = panel width, in.
d = length, in.
E = Young's Modulus, #/in.
G = shear modulus, #/in.^{2}
J = torsional stiffness constant, in.^{4}
K = buckling constant
L = length, in.
q = shear flow, #/in.
R = radius of curvature, in.
R_c = compression stress ratio
R_s = shear stress ratio
t = web or panel thickness, in.
δ = shear deflection, in.
η = stress ratio, σ/τ
θ = angle of rotation–radius
σ = normal stress, #/in.^{2}
τ = shear stress, #/in.^{2}

Subscripts

c = compression
cr = critical stress
s = shear
T = tension, total

Assume

$\pm(\Delta\delta/\delta) = \pm[G/(G \pm \Delta G)] = \pm(\Delta\tau/\tau)$
$\therefore \mp\Delta G = G \pm \Delta G[\pm(\Delta\tau/\tau)]$, $\Delta G\Delta\tau$ is neglectible
$\pm\Delta\tau = \pm\sigma(\tau/G) \quad \therefore \mp\Delta G = \pm\sigma$

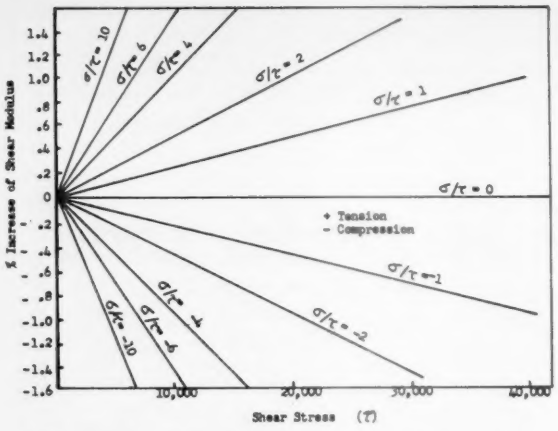
This positive or negative increase of shear stiffness may be put into graphical form (Fig. 1) by using the following equation:

$$\mp\Delta G = \pm\sigma, \quad \sigma = (\sigma/\tau)\tau, \quad \sigma/\tau = \eta$$

$$\text{per cent increase} = \mp(\Delta G/G)\,100 = (\pm\sigma/G)\,100 = (100/G)\eta\tau \qquad G = 4{,}000{,}000$$

$$\text{per cent increase} = 25 \times 10^{-6}\eta\tau \qquad (1)$$

The increase or decrease thus presented represents little or no change in the stiffness. Due to the buckling of the skins, a factor which has not been considered



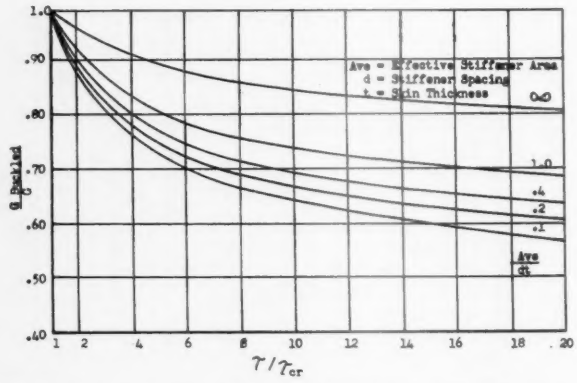


FIG. 1 (*top*). Change of shear modulus for unbuckled panels.
FIG. 2 (*bottom*). Modulus ratio for elastic web (reference 1).

to this point in the paper, an additional loss in G, takes place. This change in G is the greatest loss incurred. The equations for predicting the loss of G are derived in the following discussion:

In the analysis of this condition, it is first necessary to determine the shear stress at which shear buckling will occur. Any of the standard equations may be adapted for this purpose. In this paper an empirical equation derived by Kuhn and Levin[2] will be used. The equation is as follows:

$$300 < (R/t) < 600 \qquad \tau_{cr} = 0.1\,E(t/R) \times [1.15 + 45\,(100t/R)^4] + 6.4E(t/b)^2\,[1 + 0.8(b/a)^2] \tag{2}$$

$$(R/t) > 600 \qquad \tau_{cr} = 0.115E(t/R) + 6.4\,E(t/b)^2\,[1 + 0.8(b/a)^2] \tag{3}$$

From this equation τ_{cr} can be calculated for either flat or curved panels. A combined stress τ_{cr} can then be calculated from a combined stress relation appropriate for the panel condition. For instance, if we would use:

$$R_s^2 + R_c^2 = 1$$

Assume $K_s = 6.4\,[1 + 0.8(b/a)^2] = 7.5$, and $K_c = 6.2$

$$K_s/K_c = 1.21 \;\therefore (\tau_{cr}/\sigma_{cr}) = 1.21, \quad \eta = (\sigma/\tau)$$

Write R_c in terms of R_s.

$$R_c = 1.21\,\eta R_s$$

$$R_s^2 + 1.46\,\eta^2\,R_s^2 = 1, \quad R_s^2\,(1 + 1.46\eta^2) = 1$$

$$R_s = \sqrt{1/(1 + 1.46\eta^2)}, \quad \tau_{cr}R_s = \tau_{cr}\text{ combined} \tag{4}$$

The ratio τ/τ_{cr} combined can now be calculated. After determining τ/τ_{cr} as being greater or less than one, the following equations can be used to determine per cent increase or decrease of G. Where compression is negative and tension is positive:

$$\tau/\tau_{cr} \leq 1, \quad \text{per cent increase} = 25 \times 10^{-6}\,\eta\tau \tag{1}$$

$$1 < \tau/\tau_{cr} \leq 10, \quad \text{per cent increase} = 25 \times 10^{-6}\eta\tau - 100[1 - (\tau/\tau_{cr})^{-0.135\,(bt/A_{ve})^{0.10}}] \tag{5}$$

$$\tau/\tau_{cr} > 10, \quad \text{per cent increase} = 25 + 10^{-6}\,\eta\tau - 100\,[1 - 0.86(\tau/\tau_{cr})^{-0.076(bt/A_{ve})^{0.25}}] \tag{6}$$

Equations (5) and (6) were derived by the writer to describe the loss of G caused by buckling and are based on the curves of Fig. (2) of reference (1).

Because of the fact that the skin picks up very little stress after buckling occurs, the question arises as to what normal stress value should be used in this process to give accurate predictions of the change in G. To remedy this, static test data were used to establish an effective σ for the panel. This was found to be the average stringer or cap stress across the panel. Although the use of this stress seems unreasonable at first sight, it must be remembered that the strain present in the caps and skin represents the stress and is indicative of the degree of buckling present. By then inserting the average σ and the panel shear stress τ in the method derived, accurate predictions of torsional stiffness losses were made for several horizontal stabilizer configurations.

Utilizing this method, it was possible to derive the shear stiffness for each individual panel. With these values determined, it was then necessary to calculate the torsional stiffness (GJ) for any cross section. The torsional stiffness of a section in which a loss of G had occurred was calculated by standard closed section methods, but the minimum effective G was used in the computation. The GJ thus calculated represented the greatest portion of the total GJ. The remaining portion of the GJ was that of an open section, and was calculated with a $(G_{max} - G_{min})$. This portion of the GJ is trivial for thin airfoil surfaces and can be considered negligible. However, for a fuselage or a thick or multispar structure, it may not be neglected.

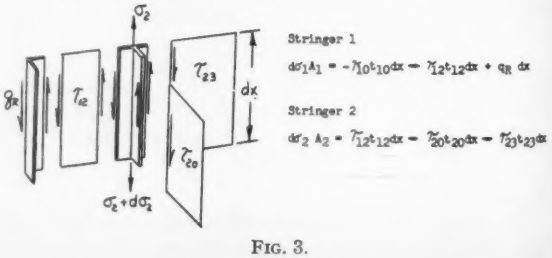


FIG. 3.

A further expansion of this analysis into the problem of thermal stress and the effects of temperature on the stiffness parameters of a structure can be accomplished with little change. The original data required to perform the analysis must now incorporate the thermal stresses superimposed upon the bending and torsional stresses caused by a given loading condition. These stresses used in combination with the reduced elastic properties of the material will produce a reduced torsional stiffness under a thermal and static loading condition. Other thermal effects which will not be expanded on here must also be taken into account. A discussion of these effects can be found in reference 3.

Application of the Analysis

The loss of torsional stiffness as analyzed in the preceding discussion has varied effects on an aircraft type structure. The method of application of this analysis will be determined by the degree of accuracy required and the structural effects to be accounted for. Appendix 1 presents the method of analysis used to determine the effect of load on torsional stiffness directly. This analysis is sufficient as a preliminary estimate of the situation and can be performed with a minimum loss of time and effort. A more refined method of performing the discussed analysis is to incorporate it into an IBM program for analyzing the general aircraft structures problem. At the present time, most aircraft manufacturers have an IBM program for the computation of stresses in the general aircraft type structure. The discussed analysis is well suited for incorporation into such a program for the refinement of both the structural analysis itself and the loss of torsional stiffness. For further refinement, a correction for bending stiffness can also be incorporated into the program. With the stiffness corrections derived from the previous run, the program can be rerun until convergence is evident. The result is a more correct stress analysis since it displays the effects due to loss of structural stiffness.

Discussion of Test Results

Tests were run to establish torsional stiffness loss data for comparison with the discussed analytical analysis. These tests were performed on several configurations of a production horizontal stabilizer.

The analytical analysis compared very closely with results obtained from the static tests. A comparison of one of the stabilizer configurations is given in Fig. 5. The different horizontal stabilizer configurations consisted of modifications of the production stabilizer by adding extra ribs and a heavier skin. Losses for these modified configurations were first predicted by the analytic method and then tested for comparison. The results of these comparisons were within the accuracy of the tests as were those of Fig. 5.

An actual flutter test of the production horizontal had been performed by sled tests of the full scale stabilizer previous to the development of the discussed

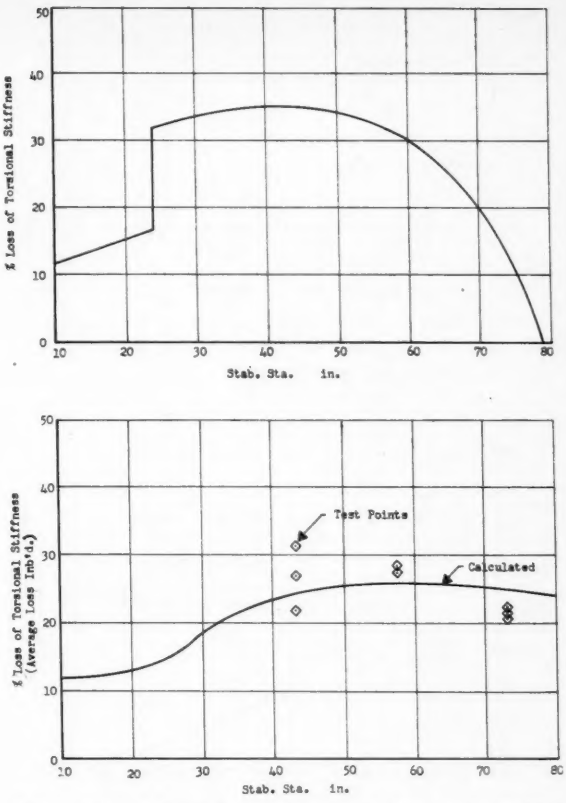


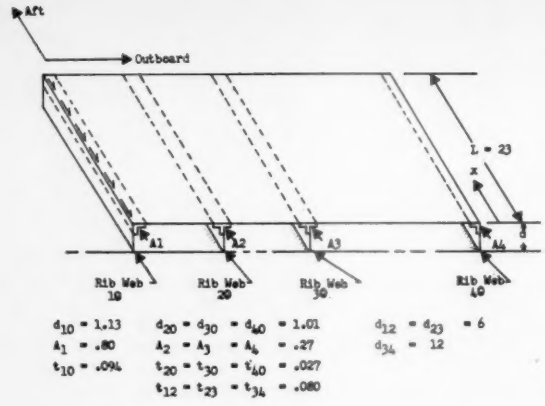
Fig. 4 (*top*). Percentage loss of torsional stiffness vs. stabilizer station from results calculated in Table 2.
Fig. 5 (*bottom*). Comparison of test data with calculated data.

analysis. There had also been a case of flutter on a test airplane with the same stabilizer configuration. In comparing the flutter speeds obtained on these occasions, a discrepancy was observed. The speed at which flutter had occurred on the airplane was considerably higher than the speed at which it occurred on the sled tests. This discrepancy remained unexplained, except as a parameter between sled tests and the actual flight conditions, until the loss of torsional stiffness study was begun. At this time the recorded loads from the two flutter cases were used to calculate an effective GJ at the time flutter occurred. Upon putting these new data into the theoretical flutter analysis, a difference of flutter speed for the two cases was predicted within engineering accuracy of the actual difference.

Based on these comparisons, it is felt that the discussed analysis is a very good tool with which the structures engineer may predict with greater accuracy the structural stiffness of any given aircraft type structure.

Rib Bending Losses

The problem of torsional stiffness loss due to rib bending has become most prevalent since the advent of the flying tail as used on high-speed aircraft. This loss has been considered to some extent in the past for structural and flutter analysis. The considerations to this time have, in general, been those of assuming a



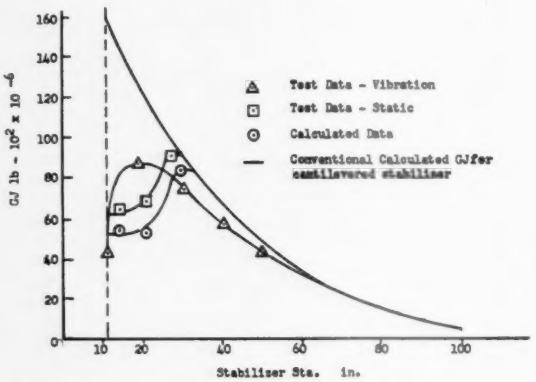

GJ lb - 10^2 x 10^{-6}
Test Data - Vibration
Test Data - Static
Calculated Data
Conventional Calculated GJ for cantilevered stabilizer
Stabilizer Sta. in.

FIG. 6 (*top*). Diagram of equivalent structure.
FIG. 7 (*bottom*). Rib bending loss of GJ vs. stabilizer station.

decreased torsional stiffness or using stiffness data derived from vibration tests. The aforementioned method has proved to give calculated data from vibration analysis matching that data obtained from vibration tests. The design engineer still has the problem of assuming stiffness values. A more accurate and simple way of predicting stiffness losses caused by rib bending is a necessary tool of the design engineer who has no actual structure to work with.

With this problem in mind, static tests were initiated to obtain stiffness losses caused by rib bending in a flying tail type structure. In conjunction with these tests a theoretical analysis was initiated in an attempt to predict the extent of rib bending losses theoretically. This theoretical analysis is based on a shear-lag method, the solution to which was accomplished on the IBM 704 computer. It is based on the assumption that a shear flow placed around the close out rib will be partially redistributed outboard to other ribs. This redistribution is carried out by shear lag methods.[4] A simplification of the structure involved may be necessary as shown in Fig. 6. The fixity of the panels and stringers along the aft edge is due to the heavy carry-through structure. The rib webs are fixed to account for the symmetry of the structure. First equilibrium equations are written for the stringers (Fig. 3).

By equating the panel shear strain and the stringer normal strain for any increment we derive the following equations:

Stringer 1 and Rib Web 1–0

$$d\tau_{10}\, d_{10}/G = -(\sigma_1/E)dx \quad \therefore (d\tau_{10}/dx) = G\sigma_1/E\, d_{10}$$

Stringer 1 and 2 Panel 1–2

$$d\tau_{12}\, d_{12}/G = -[(\sigma_1 - \sigma_2)/E)]dx\ (d\tau_{12}/dx) = (G/E\, d_{12})\ (\sigma_1 - \sigma_2)$$

etc. This is done for each combination of stringers and shear panels to obtain a total of seven equations in $d\tau/dx$. These seven equations in $d\tau/dx$ are differentiated and the equilibrium equations substituted in for $d\sigma/dx$ in each case. This results in seven second order differential equations as follows:

$$d^2\,\tau_{30}/dx^2 = -\tau_{23}(Gt_{23}/A_3E\, d_{30}) + \tau_{34}(Gt_{34}/A_3E\, d_{30}) + \tau_{30}(Gt_{30}/A_3E\, d_{30}) \quad (7)$$

$$d^2\,\tau_{40}/dx^2 = -\tau_{34}(Gt_{34}/A_4E\, d_{40}) + \tau_{40}(Gt_{40}/A_4E\, d_{40}) \quad (8)$$

$$d^2\,\tau_{20}/dx^2 = -\tau_{12}(Gt_{12}/A_2E\, d_{20}) + \tau_{20}(Gt_{20}/A_2E\, d_{20}) + \tau_{23}(Gt_{23}/A_2E\, d_{20}) \quad (9)$$

$$d^2\,\tau_{10}/dx^2 = +\tau_{10}\,(Gt_{10}/A_1E\, d_{10}) + \tau_{12}(Gt_{12}/A_1E\, d_{10}) - q_R(G/A_1E\, d_{10}) \quad (10)$$

$$d^2\,\tau_{12}/dx^2 = \tau_{10}(Gt_{10}/A_1E\, d_{12}) + \tau_{12}(Gt_{12}/Ed_{12})\ [(1/A_1) + (1/A_2)] - \tau_{20}\,(Gt_{20}/A_2E\, d_{12}) - \tau_{23}(Gt_{23}/A_1E\, d_{12}) - q_R\,(G/A_1E\, d_{12}) \quad (11)$$

$$d^2\,\tau_{23}/dx^2 = -\tau_{12}(Gt_{12}/A_2E\, d_{23}) + \tau_{20}(Gt_{20}/A_2E\, d_{23}) + \tau_{23}(Gt_{23}/Ed_{23})\ [(1/A_2) + (1/A_3)] - T_{34}(Gt_{34}/A\ E\ d) - \tau_{30}\,(Gt_{30}/A_3E\, d_{23}) \quad (12)$$

$$d^2\,\tau_{34}/dx^2 = -\tau_{23}(Gt_{23}/A_3E\, d_{34}) + \tau_{30}(Gt_{30}/A_2E\, d_{23}) + \tau_{34}(Gt_{34}/E\, d_{34})\ [(1/A_3) + (1/A_4)] - \tau_{40}\,(Gt_{40}/A_4E\, d_{34}) \quad (13)$$

The boundary conditions used in the solution of these equations are as follows:

$$\tau_{20} = \tau_{30} = \tau_{40} = \tau_{12} = \tau_{23} = \tau_{34} = 0, \quad \text{at } x = L$$
$$\tau_{10} = q_{R/t_{10}}, \text{ at } x = L$$
$$d\tau_{10}/dx = d\tau_{20}/dx = d\tau_{30}/dx = d\tau_{40}/dx = d\tau_{12}/dx = d\tau_{23}/dx = d\tau_{34}/dx = 0, \quad \text{at } x = 0$$

The results given in Appendix 2 were derived from the above solution for rib bending. Transforming these bending deflection values into angles of rotation is the next step to the final solution for the effective reduction in GJ. By imposing these angles on a curve of angular rotation versus span for the surface, new GJ values can be calculated from the slope of this curve in the effected area. Reductions in area under the GJ curve from calculated data compared very closely with results obtained during vibration and static tests. The only discrepancy in agreement between the three groups of data is the distribution of the area, and only the vibration tests disagree on this point.

Discussion of Test Results

A production stabilizer used in the preceding tests for loss of torsional stiffness caused by buckling was

again used to establish rib bending losses. Another approach to the tests was used to isolate the rib bending losses from other factors.

More data on rib bending losses were derived from vibration tests in conjunction with a vibration analysis of the structure. A reduced GJ curve was predicted by trial and error which, when put into the theoretical analysis, produced vibration data which compared very well with the vibration tests. Results of these two test methods are compared in Fig. 7 with the theoretical values calculated in Appendix 2 of this paper. This comparison shows good agreement between the static test and calculated effective GJ. The agreement of the data derived by the vibration tests is good, as far as overall percentage loss in area under the GJ curve, but does not agree with the distribution of this loss in area. From these comparisons it is evident that the discussed analyses are satisfactory for use by the design engineer to establish the basic configuration of the structure until a future time at which he can prove the design by static tests.

Appendix 1

Stresses are given for a maximum symmetrical bending condition with the upper surface in tension (Table 1).

Equations 1 through 6 derived in this paper expressing the loss of torsional stiffness caused by buckling are arranged into tabular form and the results are put down in Table 2 for the loading condition described in Table 1.

The results of Table 2 are plotted in Fig. 4 as the loss of GJ vs. stabilizer station. These results were transformed into average per cent loss of GJ inboard vs. stabilizer station for comparison with the test data as shown in Fig. 5.

Table 1

Sta.	$\sigma_{Ten.}$	$\tau_{Ten.}$	$\sigma_{comp.}$	$\tau_{comp.}$
23.5	10030	4380	−26700	5010
36.0	10330	1720	−28200	1940
50.0	8310	1100	−19500	1130
65	4890	360	−10700	410

Appendix 2

The results of the IBM solution were used to calculate shear flows in the ribs. The shear flows thus calculated were used to calculate rib bending moment and deflections. The deflections are used to calculate the effective rotation of the ribs. These calculations are accomplished by taking the results of the simplified structure and placing them on the original structure. The resulting $GJ_{effective}$ will be compared with test results.

Deflections at the leading edge of the ribs were calculated, resulting in:

Sta 11.06 = 0.15135 in., Sta 17.06 = 0.08057 in.
Sta 23.53 = 0.01128 in., Sta 36.00 = 0.001046 in.

The effective rotations are then calculated as:

Sta 11.06 = θ/L = 0.15135/23 = 0.00658 rad.
17.06 0.00350
23.53 0.00049
36.00 0.000045

GJ of section without losses from Sta 11.06 to 17.06 = 141×10^6 lb.in.^{2}

T = 44,000 in.#

$$\theta_{loss} = \theta_{11.06} - \theta_{17.06}$$

$$\theta_{loss} = 0.00658 - 0.0035 = 0.00308 \text{ rad.}$$

$\theta_1 = TL/GJ = (44{,}000 \times 6.0)/(141 \times 10^6)$ = 0.00188 rad.

(*Continued on page 64*)

Table 2

① Sta.	② σ_c	③ τ_c	④ t	⑤ b	⑥ a	⑦ R	⑧ A_m	⑨ .8 b/a +1	⑩ 6.4 x ⑨ / K_s	⑪ $(t/b)^2/(④/⑤)^2$	⑫ ⑩ x ⑪ x E / τ_{cr}	⑬ ②/③ //	⑭ ⑩ / K_s / 6.2 / K_c	⑮ (⑬ x ⑭)^2	⑯ $\frac{1}{1+⑮}$	⑰ $\sqrt{⑯}$ / R_s
11.0																
17.0	-26700	6010	.081	6	15	∞	.27	1.32	8.45	.000182	15400	5.33	1.36	52.5	.0187	.137
23.5	-26700	5010	.081	6.5	21			1.25	8.00	.000155	12400	5.33	1.33	50.4	.0195	.140
36.00	-26950	3475	.081	12.5	20			1.50	9.60	.000042	4030	7.76	1.60	154.0	.00645	.0804
50.5	-23350	1535	.081	14.5	18			1.64	10.5	.000031	3250	15.2	1.75	708	.00141	.0376
65	-15100	770	.081	14.5	16			1.72	11.0	.000031	3410	19.6	1.83	1290	.000775	.0278
79.5	-5350	205	.081	13	14.5	∞	.27	1.72	11.0	.000031	3750	26.1	1.83	2280	.000439	.0210

			$\tau/\tau_{cr} \leq 1$		$1 < \tau/\tau_{cr} \leq 10$					$\tau/\tau_{cr} > 10$					
① Sta.	⑱ ⑫ x ⑰ τ_{cr} Comb.	⑲ ③ / ⑱ τ/τ_{cr}	⑳ 25×10^{-6} x ③ x ⑬	㉑ bt/A_m ⑤x④/⑧	㉒ (㉑)$^{.19}$	㉓ -.135x ㉒	㉔ (⑲)$^{.23}$	㉕ 100(1- ㉔)	㉖ ⑳ - ㉕	㉗ (㉑)$^{.25}$	㉘ -.076x ㉗	㉙ (⑲)$^{.29}$	㉚ .86 x ㉙	㉛ 100(1- ㉚)	㉜ ⑳ - ㉛
11.0															
17.0	2110	2.37	-.67	1.8	1.118	-.151	.878	12.2	-12.9						
23.5	1735	2.89	-.67	1.95	1.135	-.153	.850	15.0	-15.7						
36.0	324	10.7	-.67	3.75						1.392	-.1058	.778	.669	33.1	-33.8
50.5	122	12.6	-.58	4.35						1.444	-.1096	.758	.652	34.8	-35.4
65	95	8.10	-.38	4.35	1.322	-.178	.689	31.1	-31.5						
79.5	79	2.60	-.134	3.90	1.295	-.175	.846	15.4	-15.5						

After many years of study, a design philosophy for high-lift BLC airplanes has been developed. This paper summarizes such a design concept and discusses problems connected with the development of BLC STOL aircraft.

Design Considerations for BLC STOL Airplanes

Fred G. Wagner

Convair, A Division of General Dynamics Corporation

SINCE PRANDTL'S 1904 PAPER on boundary-layer theory and his demonstration of BLC, more than 50 years of research in this field has been done.[1,2] Boundary-layer control wind-tunnel tests of the 1920 and 1930 years provided the designer with promising information. Flight tests of experimental suction airplanes proved the high-lift BLC principle.[3] The improvements measured in take-off and landing checked with theoretical studies. Furthermore, no serious stability and control difficulty was encountered with the suction airplanes.

Consequently the industry undertook the development of BLC airplanes in the 1930's and 1940's. Studies on BLC airfoils, ducting, and pumping systems resulted in the design concept of spanwise combined suction and blowing using jet pumps as an air mover. The whole apparatus fitted in the wing aft of the rear spar. Two large prototype BLC airplanes with such BLC systems were built in Europe.[4–6] The end of World War II prevented complete flight testing of these airplanes. An evaluation of the first of these two aircraft in this country recommended the continuation of this development.[7]

Suction and blowing tests of the early 1940's resulted in $C_L \geqq 10$. Reports of this time give data on trailing-edge suction, on jet flap models, etc.[8] Developments of the last 10 years are, for instance, porous suction, chordwise combined suction-blowing, and renewed work on the jet flap principle.

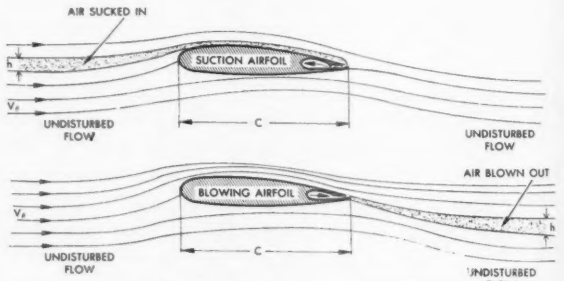
The recent interest in STOL and VTOL concepts has resulted in many technical papers.[9–11] Mass produced BLC transports are predicted in the 1957 report for the President's Aviation Facilities Planning Group.[12]

BLC TEXTBOOK IS NEEDED

In this paper, the general term BLC is used throughout. Different systems are distinguished by following closely the definitions used in reference 13.

Boundary-layer control can mean in aeronautical engineering as much as the vacuum tube in electrical engineering. The vacuum tube overcomes the limitations of "passive" networks of resistors, condensers, and chokes. Vacuum tubes used with passive elements make "active" systems featuring power input at each tube. In this way the electrical engineer obtains performance unthinkable with passive networks. Following this electrical analogy, BLC changes the passive system (conventional airplane) to an active system (BLC airplane). The BLC airplane features power input into the airflow not only by the propulsion engines but also power injection by blowing or sucking through openings in the lifting surfaces.

The electrical engineer uses for the choice of the appropriate tube such a book as the *RCA Tube Manual*. The aeronautical engineer needs a BLC textbook to find exactly the kind of BLC he wants. Since such a book is not available at present, the first step in preparation of such a textbook is the definition and description of presently available BLC systems. The following arrangements are known as useful or potentially useful in the near future.



FLOW COEFFICIENT $C_o = \frac{h \times b \times V_o}{b \times c \times V_o} = \frac{h}{c} = \frac{Q}{V_o S}$

S = BLC REFERENCE AREA = b × c

Q = AIR QUANTITY SUCKED IN OR BLOWN OUT

FIG. 1. Definition of the BLC flow coefficient.

Mr. Wagner is a Senior Aerodynamics Engineer.

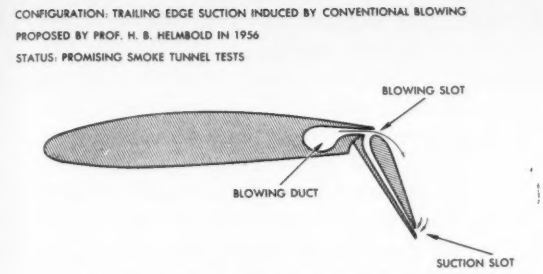

CONFIGURATION: TRAILING EDGE SUCTION INDUCED BY CONVENTIONAL BLOWING
PROPOSED BY PROF. H. B. HELMBOLD IN 1956
STATUS: PROMISING SMOKE TUNNEL TESTS
BLOWING SLOT
BLOWING DUCT
SUCTION SLOT

FIG. 2. Chordwise combined suction-blowing.

Suction Airfoils

Partial or complete removal of the boundary layer by suction on the upper surface results in nearly potential flow lift. The sink effect of suction adds further to the circulation lift. The basic flow without suction is a parallel stream with a doublet and a vortex. The Kutta-Joukowski condition of a streamline leaving the trailing edge controls the vortex strength. The suction superimposes the sink-flow upon the basic flow. Therefore, the suction changes the vortex strength with the sink strength in accordance with the Kutta-Joukowski condition. Suction at the bend from the airfoil to the flap is an effective measure to prevent flow separation. The lift increment from the sink effect is dependent on the suction slot location and the suction flow coefficient C_Q (see also Fig. 1).

More theoretical and experimental work has to be done in order to predict the total lift of different suction systems. Helmbold's theory on circulation lift[14] and Ringleb's study on sink lift[15] are samples of the work done so far. Considerable work on suction is being done in the Ames Laboratories of NACA. Investigations under way include theoretical studies and smoke tunnel and electrical tank experiments at Princeton University. These studies include such new concepts as suction on the lower side of an airfoil behind a split flap.

Blowing Airfoils

Blowing increases circulation lift by suppression of flow separation, by jet induction, and by jet momentum lift. A large number of test results are available. The blowing wing theory is still in the development phase.[16–19] NACA's theoretical and experimental work in this field is mainly done at Langley Field.

Combined Suction-Blowing Airfoils

The combination of sucking-blowing requires less pumping power for a given lift coefficient than all-suction or all-blowing BLC. Nose suction (or blowing) combined with rear blowing (or sucking) is a good arrangement under conditions of critical leading-edge flow. The French jet pump driven suction-blowing system over two rear flaps is flight tested in the Breguet BLC Vulture airplane. Porous suction at the flap nose with blowing in the rear of the flap and the scheme shown in Fig. 2 represent new combination systems. Trailing-edge suction combined with blowing behind a mid-chord split flap (TESBOF) showed linear increments of C_l with C_μ (reference 20).

Correlation of Design Data

The BLC test data consist of C_L, α, C_Q, and C_μ. However, the designer needs C_L vs. required air quantity and pumping power since he has to define duct sizes and BLC pumps. Reduction of wind-tunnel data to specific air quantities for different wing loadings is shown in Fig. 3. The air quantities for blowing depend on the ratio slot width s to wing chord c. The blowing quantity can be plotted for $s/c = 1$. For any ratio s_1/c_1 one has to multiply the blowing air quantity given for $s/c = 1$ by a factor $\sqrt{s_1/c_1}$. This relationship holds true only for incompressible flow. It will be shown that optimized BLC systems operate at Mach Numbers so low as to satisfy the incompressible formula $C_\mu = 2C_Q{}^2/(s/c)$.

The following equation can be used to determine the BLC pumping power (in hp.) required[5]

$$P = (1/550)\ \{Q_s q_\gamma\ (n_E + n_s) C_{Q_s}{}^2 + Q_B[q_0 n_B C_{Q_B}{}^2 + (\rho/2)\ (V_j{}^2 - V_0{}^2)]\}$$

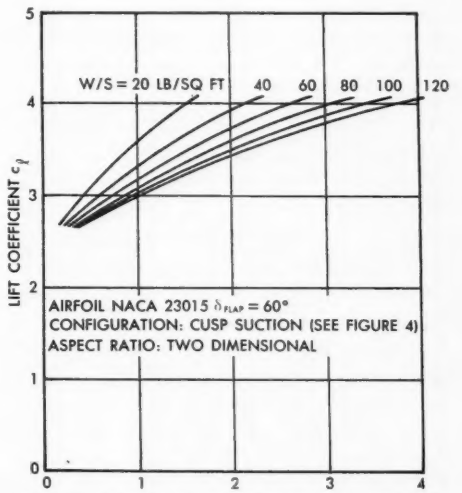
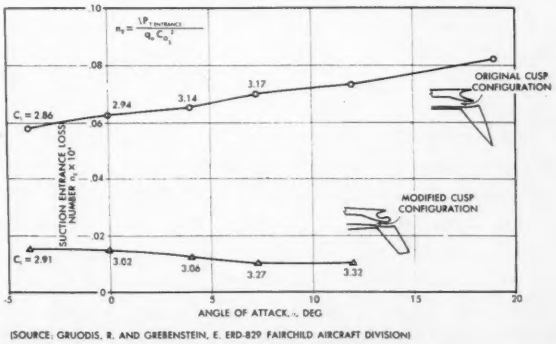


FIG. 3. C_L vs. Q required for different W/S.



(SOURCE: GRUODIS, R. AND GREBENSTEIN, E. ERD-829 FAIRCHILD AIRCRAFT DIVISION)

FIG. 4. Suction wing entrance loss.

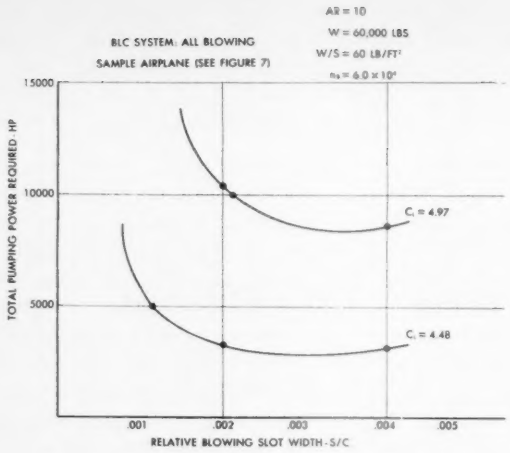


FIG. 5 Effect of blowing slot width on power.

Values of C_L, C_Q, and V_j can be obtained from plottings such as shown in the sample Fig. 3. Loss numbers may be computed from duct experiments.[21] Fig. 4 shows n_E numbers plotted vs. angle of attack. Similar plottings of all the duct component loss numbers vs. wing aspect ratio, duct shape parameters, etc., are helpful for power calculations.

Fig. 5 shows the effect of the blowing slot width (exit loss) on the pumping power. Since s/c also controls Q_B a check on the blowing quantity has to be done. For a given C_μ and C_L, changes of s/c affect the jet momentum losses from the slot to the trailing edge. Investigations of this problem are in progress. (Note that the blowing wing theory correlates C_L with $C_{\mu \text{trailing edge}}$ not with $C_{\mu \text{ slot}}$.)

Refinements of data correlations come from stability and control considerations. Conventional designs suffer lift losses due to trim. If BLC has to be applied to the tail additional pumping power is required. On the other hand slipstream or jet turning on a BLC wing can contribute very high additional lift.

Design Concept

Some recent BLC studies show doubtful low-speed improvements because of large power requirements. Pessimistic assumptions and neglect of possible weight savings on the wing, landing gear, etc., have contributed to these results.[22] These suction or blowing (jet) retrofits to existing designs do not show any real promise. Only a basically better design concept applied at the layout stage leads to practical BLC airplanes.

The chordwise combination of suction-blowing is likely to become such a concept once it is further developed. The similar spanwise combined systems represent a readily usable concept. Spanwise combined suction-blowing has advantages of small required air quantity and power, as well as simple structure.

The data and equations discussed above for the all-suction and all-blowing BLC can be used for these combined systems. The air sucked in at one span portion has to be blown out at another portion of the span. Matching of the suction and blowing air quantities can be achieved by the choice of blowing slot width and the ratio of suction to blowing wing area. Considering the simple case of the air volume flux being half the flux of all-suction or all-blowing systems reduces the dynamic pressure in the same available duct cross section to 1/4. Half the airflow at one quarter of the dynamic duct pressure results in 87.5 per cent duct pumping power saving $[(Q/2)\ (\Delta P_t/4) = P/8]$.

Since the duct losses increase with $q_{\text{duct}} = (\rho/2)\ (Q/S_{\text{duct}})^2$, the distribution of Q over 2 or more span portions in the multiple cell systems further reduces these losses. The airflow of each cell equals Q of the Arado Installation divided by N (number of cells). Therefore, the duct losses and pumping power would be reduced as $1/N^2$. The actual power required is even smaller, mainly due to the shorter ducts. A reduction factor of $1/N^{2.2}$ was found for several designs. With these values, the following comparison was done (where P_D is the pumping power required to overcome the duct losses):

(1) Combined suction-blowing $P_D = 12.5$ per cent of all-suction or all-blowing systems.

(2) Two-cell system $P_D = 2.72$ per cent of all-suction or all-blowing systems.

(3) Three-cell system $P_D = 1.11$ per cent of all-suction or all-blowing systems.

(4) Four-cell system $P_D = 0.60$ per cent of all-suction or all-blowing systems.

Note that in optimized systems (= total pumping power = minimum) the duct losses cause the major portion of the total pumping power required.

For power savings and structural simplicity the spanwise combined system represents one basic BLC design concept. For safe operation interconnected pumps are required. Pumps independent of the propulsion engines add to the safety and make equal improvements of take-off and landing possible. The use of jet pumps is a natural choice for this concept. The reliable jet pumps having no moving parts give higher safety even in case of main engine failure. Multiple nozzle jet pumps become short enough for wing installations. High-pressure hot propellants do not raise the temperature or the pressure in the ducts enough to cause difficult structural problems.

A standby system (plenum chamber, rocket fuel, etc.) can be installed if so desired for emergency cases of simultaneous failure of the prime gas producers. The high jet pump entrainment ratio $m > 10$ makes the required primary gas flow relatively small.

The low jet pump efficiency offsets somewhat the low power requirements of the basic design concept. Decisive is the total pumping power saving of the jet pump driven multiple cell systems (see Fig. 6). Jet pump investigations in the planning stage will be mainly directed toward achieving a higher efficiency than used in this figure.

The flexible scheme of the suggested jet pump multiple cell system can be applied to almost any project.

The required jet pump length restricts the number of cells in most wings to four or less. If shorter jet pumps can be developed, considerations of weight and structural complexity may still limit the number of cells. The all-suction and all-blowing BLC may serve as special installations for unusual projects.

Design Procedure

BLC affects performance and structure of aircraft to such an extent that it has to be considered in the preliminary design of the vehicle. Parametric studies shall include optimized wing (size, AR, critical M-number, etc.), BLC effects on jet and slipstream turning, stability and control in and out of ground effect, and L/D control by BLC. Moreover, the following considerations may affect the design: use of BLC installation for thrust production, pressurization, pneumatic drives, deicing, and other purposes. Weight savings can result by eliminating unnecessary parts such as thrust reverser and drag chutes and by the use of lighter flaps and landing gears. The improvement obtainable by BLC for propulsion engine out condition, gust load reduction, bad weather operation, as well as reduced tire wear, smaller required fuel reserve for missed approaches, reduced ground handling time, etc., influence the airplane layout.

Supplementing the common parametric study, the BLC data mentioned before help to reduce the actual computing work. For the relatively small BLC aircraft of high $C_{L_{max}}$ found by this method, new engines, etc., have to be selected. The BLC system can then be optimized and integrated into the design. As more BLC data become available the design procedure can be improved and refined. The cooperation of aeronautical engineers and engineers in other fields is necessary to create a BLC aircraft design method equivalent to the practical method available for conventional aircraft. The many problems in BLC development reach beyond the aerodynamic field. The potentials of BLC represent a challenge for the mathematician and the physicist in the same way as for the aircraft and engine designer.

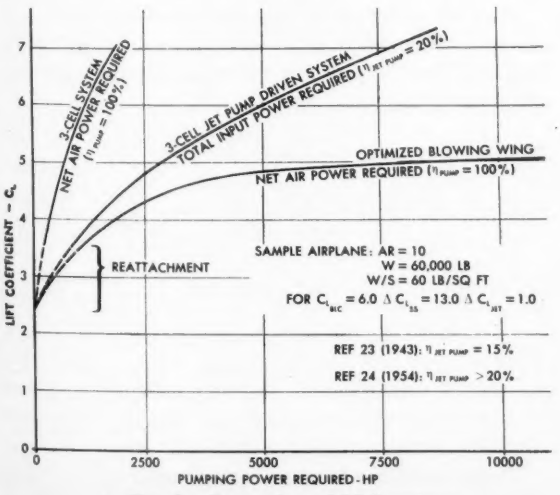

LIFT COEFFICIENT - C_L
PUMPING POWER REQUIRED - HP
3-CELL SYSTEM NET AIR POWER REQUIRED ($\eta_{JET\ PUMP}$ = 100%)
3-CELL JET PUMP DRIVEN SYSTEM TOTAL INPUT POWER REQUIRED ($\eta_{JET\ PUMP}$ = 20%)
OPTIMIZED BLOWING WING NET AIR POWER REQUIRED ($\eta_{JET\ PUMP}$ = 100%)
REATTACHMENT
SAMPLE AIRPLANE: AR = 10
W = 60,000 LB
W/S = 60 LB/SQ FT
FOR $C_{L_{BLC}}$ = 6.0 Δ $C_{L_{SS}}$ = 13.0 Δ $C_{L_{JET}}$ = 1.0
REF 23 (1943): $\eta_{JET\ PUMP}$ = 15%
REF 24 (1954): $\eta_{JET\ PUMP}$ > 20%
0
1
2
3
4
5
6
7
2500
5000
7500
10000

Fig. 6. Comparison of BLC systems.

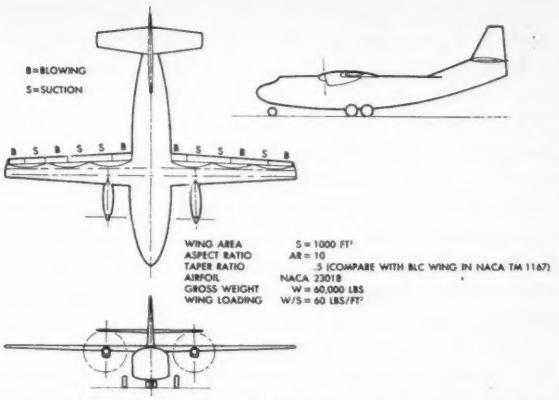

B=BLOWING
S=SUCTION
WING AREA S = 1000 FT²
ASPECT RATIO AR = 10
TAPER RATIO .5 (COMPARE WITH BLC WING IN NACA TM 1167)
AIRFOIL NACA 23018
GROSS WEIGHT W = 60,000 LBS
WING LOADING W/S = 60 LBS/FT²

Fig. 7. Paper BLC airplane, basic configuration: multiple cell BLC system.

The still primitive design method suggested can best be explained for the case of the subsonic STOL transport. STOL means: (1) Slow Take-Off and Landing, (2) Short Take-Off and Landing, and (3) Steep Take-Off and Landing. The aerodynamic requirements for STOL performance are:

(1) Extreme low-speed capabilities. (Very high C_L, very low minimum control speed.)

(2) High excess thrust at very low speed coupled with high L/D values in take-off.

(3) Very high C_L coupled with very low L/D values in the landing configuration.

The correlated data applied to the design concept can be used to satisfy the above requirements (see Fig. 7):

(1) The jet pump driven multiple cell system provides very high lift (Fig. 6). The maximum total lift for the smallest power is found by varying C_L due to BLC and computing ΔC_L due to slipstream and jet turning. Aileron effectiveness is improved by blowing. Changing the relative air quantities blown over the aileron by stick actuated valves, blowing spoilers, and variable blowing slot width are additional means of increasing aileron effectiveness. Similar measures can be applied to a BLC tail.

(2) The total thrust is the sum of the main engine thrust plus the blowing air thrust. The effective thrust component in flight path direction is a function of the downwash angle at infinity (aspect ratio, flap deflection, ground effect). High aspect ratio, elliptical lift distribution, and BLC-increased e factor keep the induced drag (main drag) small at low speed. Take-off calculations for STOL aircraft show that $C_{L_{max}}$ is only needed in the transition. A tailoring of C_L for best acceleration, transition, and climb in take-off may be necessary.

(3) Higher and staggered flap deflections (larger turning angle of slipstream and jets) in the landing configuration increase C_{D_i}. A manual or automatic switch or blowoff valves should stop the BLC on touching the ground.

Once these requirements are fulfilled the basic airplane configuration is "frozen" (compare with Fig. 7). The high-wing arrangement in connection with the low-velocity blowing jet minimizes the lift reducing ground effect. The wing is designed for elliptical lift distribution (take-off), reasonable critical Mach Number, and space requirements for fuel and BLC ducts. The turboprop engines of approximately 4,000 *e* s.hp. each give a desired $V_{max} \geqq 350$ m.p.h. The two (or more) independent BLC gas producers, in addition to the two main engines, provide added safety in case of a main engine failure.

Low-speed stall is controlled by the spanwise BLC air distribution and flap deflections. An untwisted wing can be considered since BLC is operating in low speed. The necessity of BLC on the tail depends on the tail volume and the wing BLC (ΔC_M due to ΔC_L). The small pumping job on the tail can be provided by piping from the main plenum chamber. Jet pump driven single suction-blowing systems in the horizontal and vertical tail group are suggested.

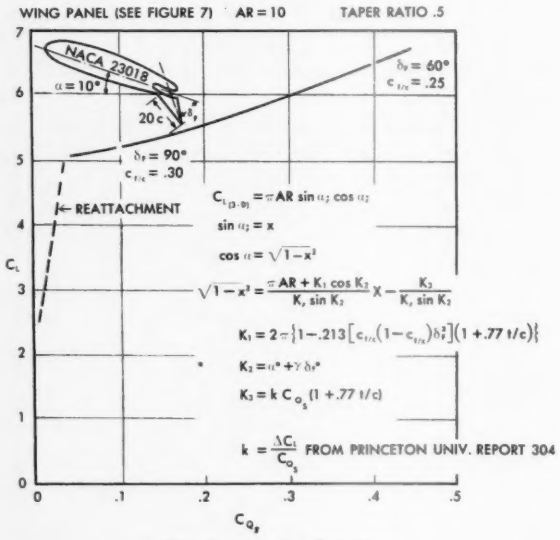

WING PANEL (SEE FIGURE 7) AR = 10 TAPER RATIO .5
NACA 23018
α = 10°
20c
δf = 90°
cf/c = .30
δf = 60°
cf/c = .25
REATTACHMENT
CL(D-0) = πAR sin α2 cos α2
sin α2 = x
cos α = √1−x²
√1−x² = (πAR + K1 cos K2)/(K3 sin K2) X − K2/(K3 sin K2)
K1 = 2π{1−.213[cf/c(1−cf/c)δf²](1 +.77 t/c)}
K2 = α° + γ δf°
K3 = k CQs (1 +.77 t/c)
k = ΔCL/CQs FROM PRINCETON UNIV. REPORT 304
CL
CQs

FIG. 8. Suction flap wing.

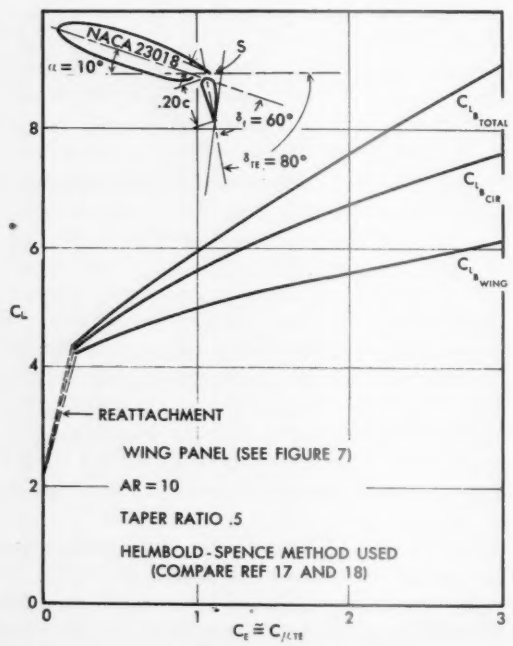


FIG. 9. Blowing wing.

An economical BLC lift coefficient of $C_L \geqq 6$ was found for the sample airplane. Slipstream turning at this high wing lift was computed to $\Delta C_{L_{SS}} \geqq 13$. The momentum lift from the exhaust jets (turning vanes installed) is $\Delta C_{L_{jet}} = 1$. The total maximum lift coefficient at $\alpha = 15°$ of $C_{L_{max}} \geqq 20$ gives a stall speed of $V_{st} \geqq 35$ m.p.h. Calculated total take-off and landing distances over the 50-ft. obstacle are well under 400 ft. The climb-out and approach angles are very steep. (Note: induced drag is produced by C_L smaller than the quoted $C_L = 6$ since this value of 6 includes jet momentum lift.)

The following assumptions are used for the sample airplane of Fig. 7:

(1) Approximately elliptical lift distribution (circulation C_l is nearly constant over the span). It follows that C_Q and C_μ values, respectively, are constant over the untwisted wing panel.

(2) Full span flaps, BLC off, results in nearly elliptical lift distribution (including area obscured by fuselage). The same lift distribution was assumed for BLC on (take-off flap setting). Hence, suction C_l (= circulation C_l) and blowing $C_{l_{B_{WING}}}$ (= circulation C_l at the wing = $C_{l_T} - C_{l_M}$) are constant over the entire span.

(3) Tapered BLC ducts for constant ratio of spanwise duct velocity to chordwise slot velocity over the span.

The optimization of the sample airplane included these steps:

(1) A refined choice of suction and blowing airfoils was made from correlated test data and theoretical work. Figs. 8 and 9 show the raw data used.

(2) The duct was designed for a maximum cross section of $S_D = 0.018c^2$ permitting rear spar locations at $0.55c$ and up to $0.30c$ flaps. A $0.24c$ flap was chosen.

(3) The optimization of power required for each of the three cells was done by computing the BLC power required and the jet pump power available using the following equations:

BLC pumping power (in hp.) required:

$$P_{BLC} = (Q_S/550)\{(n_E + n_S)\ C_{Q_s}{}^2 + [(m+1)/m]\ [n_B\ C_{Q_B}{}^2 + (\rho/2)\ (V_j{}^2 - V_i{}^2)]\}$$

Jet pump power (in hp.) available:

$$P_{jet} = W_s\ \Delta h\ \eta\ 1.415/m$$

(for details see appendix and references 23 and 24). The intersections of curves P_{BLC} with P_{jet} represent solutions for $P_{BLC} = P_{jet}$ available.

(4) Solutions for total pumping power make "optimized" subdividing of the wing into the three cells neces-

sary. However, no simple relation for tapered wings was found. Minimum power required was calculated for the wing in question by dividing in nearly equal wing area cells.

(5) Choice of gas generators results from summary plottings of power required for propellants of different energy (different Δh).

The choice and location of all the components is of course influenced by other than the above considerations. Duct mock-up testing is as useful for BLC systems as model wind-tunnel testing for airplane developments.

Conclusions

High-lift BLC systems and correlations of available data are discussed. The state of the art suggests the flexible concept of a multiple cell system. The use of this concept in a new design procedure leads to practical STOL BLC airplanes.

Future research and development work has to be done on basic suction and blowing configurations. Such investigations may result in a refined or even different concept. The design procedure itself must be improved to make better use of the existing or future BLC concepts. Further research on aerodynamical features of BLC such as lift limitations, stability and control, ground effect, etc., is as necessary as the component development of high efficiency jet pumps and low loss ducts.

Appendix

Determining of BLC Pumping Power

BLC pumping power (in hp.) required:

$$P_{\text{BLC}} = (Q_s/550)\ \{(n_E + n_s)C_{Q_s}{}^2 q_0[(m+1)/m] \times [n_B\ C_{Q_B}{}^2 q_0 + (\rho/2)\ (V_j{}^2 - V_0{}^2)]\}$$

Jet pump power (in hp.) available:

$$P_{\text{jet}} = \eta W_s\ \Delta h\ 1.415/m$$

where

Q = $(W/\rho g)$ volume flow, cu.ft./sec.
W = mass flow, lbs./sec.
m = W_s/W_j = jet pump entrainment ratio
n_E = $\Delta P_t/q_0 C_Q{}^2$ = total pressure loss number
Δ_{P_t} = total pressure loss, lbs./sq.ft.
q_0 = $(\rho/2)\ V_0{}^2 = (W/S)\ (1/C_L)$ = flight dynamic pressure, lb./sq.ft.
V_0 = $\sqrt{W2/S\rho C_L}$ = flight speed, ft./sec.
C_{Q_B} = $(Q_B/S_B\ V_0) = \sqrt{C_\mu (s/c)/2}$ = blowing flow coefficient
C_μ = $2\ C_{Q_B}{}^2/(s/c) = W_B V_j/g q_0 S_B$ = blowing momentum coefficient
s = blowing slot width, ft.
c = wing chord, ft.
S_S = suction wing reference area, sq.ft.
S_B = blowing wing reference area, sq.ft.
V_j = $[C_{Q_B}/(s/c)]V_0$ = blowing jet velocity, ft./sec.
$(\rho/2) \times (V_j{}^2 - V_0{}^2)$ = blowing jet total pressure loss, lb./sq.ft.
η = jet pump efficiency
Δh = enthalpy difference available in expansion of jet pump propellant, B.t.u./lb.
1.415 = conversion factor, B.t.u./sec. = 1.415 hp.

Main parameters for P_{BLC} are: (a) area ratio S_S/S_B; (*b*) relative blowing slot width s/c; (*c*) C_L (C_Q, C_μ); (d) n-numbers from suction slot and duct geometry; and (e) flap deflection δ_F.

Main parameters for P_{jet} are: (a) jet pump efficiency η; (b) enthalpy difference Δh; and (c) entrainment ratio m.

$$m = W_S/W_J = [\Delta h\ \eta\ \rho\ g\ 778.3 - (P_{t_M} - P_0)] \div (P_{t_M} - P_{t_S})$$ (effect of Δh and η on m)

where 778.3 = conversion factor 1 B.t.u./sec. = 778 lb./sec.

$$\text{Efficiency } \eta = P_{\text{out}}/P_{\text{in}} = [m(P_{t_M} - P_{t_S}) + (P_{t_M} - P_0)]/\Delta h\ \rho\ g\ 778.3$$

$$\text{Power input (in ft.lb./sec.) } P_{\text{in}} = W_s \Delta h\ 778.3/m$$

$$\text{Power output (in ft.lb./sec.) } P_{\text{out}} = Q_s\ (P_{t_M} - P_{t_s}) + Q_J (P_{t_M} - P_0)$$

Indexes are: J, primary jet; S, suction; B, blowing; E, entrance (suction slot); o, ambient conditions; and M, mixture ($B = S + J$).

Note that the above jet pump efficiency covers the diffuser losses. The duct pressure loss number n_B in the above P_{BLC} formula must not contain a diffuser loss portion.

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Loss of Torsional Stiffness (Continued from page 57)

$$\theta_T = 0.00188 + 0.00308 = 0.00496 \text{ rad.}$$

$$GJ_{\text{effective}} = TL/\theta = (44{,}000 \times 6)/.00496 = 53.2 \times 10^6 \text{ lb.in.}^2$$

GJ of Section without losses from Sta 17.06 to 23.53 = 118×10^6 lb.in.^{2}

Rotation due to Rib Bending

$$\theta_{16\cdot06} - \theta_{23.53} = 0.0035 - 0.00049 = 0.00301 \text{ rad.}$$

$T = 44{,}000$ in.#

$$\theta_1 = (44{,}000 \times 6.5)/(118 \times 10^6) = 0.00242 \text{ rad.}$$

$$\theta_T = 0.00242 + 0.00301 = 0.00543 \text{ rad.}$$

$$GJ_{\text{effective}} = (44{,}000 \times 6.5)/0.00543 = 52.7 \times 10^6 \text{ lb.in.}^2$$

GJ of Section without losses from Sta. 23.53 to 36 = 89×10^6 lb.in.^{2}

Rotation due to Rib Bending

$$\theta_{23.53} - \theta_{36} = 0.0049 - 0.00045 = 0.00445 \text{ rad.}$$

$T = 44{,}000$ in.#

$$\theta_1 = (44{,}000 \times 12.5)/(89 \times 10^6) = 0.00618 \text{ rad.}$$

$$\theta_T = 0.00618 + 0.000445 = 0.006625 \text{ rad.}$$

$$GJ_{\text{effective}} = (44{,}000 \times 12.5)/0.006625 = 83 \times 10^6 \text{ lb.in.}^2$$

Plotting these effective GJ values on a plot (Fig. 7) of calculated GJ along with values derived from test results gives reasonably good correlation of the rib bending losses.

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A program is outlined for improvement and demonstration of the reliability of liquid rocket propulsion systems and similar equipment using development test data.

Reliability Achievement and Demonstration

in a Development Program

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Space Technology Laboratories

THE PACE REQUIRED in development of technically advanced equipment frequently results in achievement of superior performance by use of new and unusual engineering techniques. These techniques are all too frequently accompanied by new and unusual problems resulting in inadequate reliability. The attainment and demonstration of reliability required for operation is fast becoming recognized as an integral part of a development program for advanced equipment. While the need for reliability is almost universally recognized, there is little agreement on how to achieve and demonstrate it. The purpose of this paper is to present a reliability program and statistical analysis for use when specified reliability must be achieved and demonstrated as quickly and economically as possible. Speed and economy are attained by special use of data from development tests to avoid routine repetitive testing solely for reliability demonstration. Reliability programs of this type are presently being used for the propulsion systems of Atlas, Titan, and Thor Air Force Ballistic Missiles.

A development program is generally divided into three phases. The initial goal is achievement of the desired performance. This is followed by elimination of repetitive design-type failures. Finally, it is necessary to reduce the occurrence of random failures to a tolerable frequency. The last phase is usually considered reliability improvement. Methods for reliability improvement are not standardized. New equipment is considered ready for reliability development when it functions properly as a system and if all components operate within design tolerances. System failures may then be related to components which can be redesigned and replaced if necessary. This situation has fostered a widely held belief that system reliability can be achieved best by adequate component testing. The difficulty with such an approach is best illustrated by an example.

Suppose that equipment with 20 parts is required to show a 50 per cent probability of at least 95 per cent reliability. The minimum amount of testing which can demonstrate this reliability is the number of successive tests without failure. This number can be calculated from the formula:

$$\text{number of tests} = \frac{\log\ (1\text{-confidence level})}{\log\ (\text{reliability})}$$

In this example 14 consecutive successful system tests would be required to demonstrate reliability requirements. If all 20 parts are assumed to have equal reliability, each must have a probability of 50 per cent of at least 99.75 per cent reliability. A minimum of 270 tests are required to demonstrate such reliability. A program of this type might be reasonable if all 20 components are identical. However, if the components are all different, a total of 5,400 tests would be the minimum required. The contrast between 14 system tests and 5,400 component tests to demonstrate the same level of reliability is illustrative of the problem encountered with equipment consisting of many different components. In addition, component testing assumes perfect duplication of system environment and neglects component interactions.

The reliability program presented here was originally developed for large liquid rocket propulsion systems. Such systems have a large number of different parts. Costs are high for both system and component tests. The type of equipment dictates a program with limited numbers of tests and requiring maximum utilization of all test data. The methods developed are felt to be applicable to many other types of equipment. They should be useful whenever equipment consists of many dissimilar components and satisfactory perform-

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ance is judged by attributes and output limits rather than distribution of output variables. The equipment must be suitable for trials of discrete operating cycles each of which can be judged a success or a failure.

System Test Simulation

The desired end product of a reliability improvement program is equipment with a specified probability of operating properly when used in service. The only way to find out whether equipment is adequately reliable is to try it a sufficient number of times. In a development program large numbers of tests are ordinarily conducted to obtain engineering information. It is proposed that data from these tests be used for periodic reliability estimation, as well as for ultimate demonstration of required reliability. Such use of engineering test data requires special statistical analysis techniques and careful use of data to be sure that tests represent adequate simulation of operating conditions.

In order that eventual service operation be properly simulated, system testing must consider performance, inputs, environment, test duration, and previous equipment operation. In certain cases all these quantities need not be simulated in the same test. The simulation required in order to provide a valid reliability test depends on the nature of the equipment and previous test experience. A continuous examination of the extent to which each test simulates some phase of service operation is one of the most important aspects of management of this type of reliability improvement program.

Equipment undergoing a functional test has certain inputs and outputs. The output is usually considered performance. There are specified tolerances within which performance parameters must fall in order that equipment operation be considered successful. Specified performance is almost always a required condition in order that a test be considered adequate simulation of service conditions. In order to achieve specified performance, it is necessary to provide specified input quantities to the equipment under test. These inputs may be electrical power, fuel, coolants, control signals, or other quantities. The failure to provide inputs, as specified, means that a test should not be considered a valid trial of equipment functioning.

Many types of equipment are required to operate under special environmental conditions such as heat, cold, moisture, or vibration. Some conditions are due to climatic and seasonal variations while others are due to adjacent devices or the equipment itself. The environmental extremes under which equipment must operate are often specified as special test conditions. For military equipment, such tests are part of the requirements for qualification of a design. A portion of the testing performed in a development program must be devoted to achievement of satisfactory operation under artificially adverse environments. Usually there are no specific reliability requirements for equipment when run exclusively under environmental conditions.

Many types of high-performance equipment are required to operate only for a specific duration. For example, a guided missile propulsion system has a life cycle determined by the missile mission. A test providing maximum simulation of missile flight would require full duration propulsion system operation. In performing such tests on many kinds of equipment, it is found that failures occur most frequently in the early portion of the test period and infrequently toward the end. With such equipment, it is often desirable to run only a portion of the tests until the critical failure period has passed. In such cases, it is proposed that results of short runs be incorporated into the regular reliability record up to a specified fraction of the total tests for any period. The permissible fraction of short runs to be used for reliability calculations must be decided on the basis of details of equipment test history. If tests show that failures occur at random throughout the duration of runs or bunch toward the end, the use of any short runs in a reliability record would be undesirable since they would cause biased results.

In a development program where equipment can be tested repeatedly, the amount of operating time accumulated by individual parts may become a factor in reliability. Some parts tend to wear out faster than others so a detailed log is required to keep track of equipment undergoing tests. Frequently a maximum useful life can be determined for parts by noting if failure rates start to increase as equipment accumulates operating time. Articles which exceed their useful lives should be withdrawn from the test program. Occasionally an equipment shortage requires that a test article be used beyond its useful life. In such cases, failures attributable to these articles should void the trial for the reliability record. The use of test articles beyond a demonstrated useful life should be regarded as a temporary emergency measure. If the practice becomes widespread in a program, it will jeopardize the usefulness of the reliability data obtained.

Failure Criteria

An important part of the type of reliability program under consideration is the selection of criteria for deciding whether a trial is a success or a failure. Special criteria of this type are frequently employed in the engineering phases of a development program. The reliability program criteria need not necessarily be the same. The criterion used in a reliability program should consider the intended purpose of equipment in service. A widely applicable criterion is that a test can be considered a success for reliability purposes if similar operation in service would have permitted successful accomplishment of the intended equipment purpose. For equipment which performs a complete cycle of operation this means that a successful trial must include a normal start, stable operation within specified performance limits for a planned duration, and a normal controlled shut-down. This type of criterion is generally applicable to guided missile subsystems and is particularly useful for liquid rocket

propulsion systems. Devices which do not have a definite operating cycle may require different criteria to define successful operation. Reliability analysis methods intended for individual trials may not be suitable for continuously operating equipment. Many of the program techniques presented here would not then be applicable.

Failures should always be localized as closely as possible in order to implement proper analysis and design correction. Failures can occur in several ways. Parts can fail due to: out-of-tolerance fabrication, a local environment different from design assumptions, failure of some adjacent part, or in a purely random fashion not associated with a definite cause. The first of these is a quality control problem which must be corrected before reliability data can be considered a valid representation of equipment design. Failure due to local environment is an engineering design problem which should be solved by normal development procedures. A failure induced by an adjacent part should be attributed to the part which fails originally. A reliability program should be concerned primarily with random failures of properly fabricated parts operating in their normally expected environments. From an engineering point of view, such parts are almost satisfactory because they usually function properly. The purpose of reliability improvement is to minimize occasional failures in designs which satisfy all other requirements.

Sometimes a failure results from progressive unfavorable interactions of several parts. Generally this type of failure indicates a system weakness and may mean that the equipment is not ready for a reliability program. More typically failures are attributable to a specific part in the equipment. For the purposes of a reliability program of this type, it is convenient to assume that all failures have single local sources. This assumption facilitates statistical analysis of failure occurrence and subsequent corrective action. It also leads to a useful means for classification of equipment part reliability.

System Testing

As soon as a part fails in a system test, a separate reliability record should be started for it. Each part which has caused a failure then warrants individual reliability analysis while parts which have not failed remain undifferentiated within the total system. A convenient nomenclature for this procedure is to call each failure source an "element" of a system while the remaining portion, comprising parts which have not failed, is called the "surviving system." Separate records are kept for each "element" in order to determine statistically the most critical sources of failure. This procedure avoids the need for arbitrary division of a system into components and for arbitrary assignment of reliability goals for each component.

The assignment of failures to "elements" assumes that failure sources are definitely isolated. In a case where a test fails but the source cannot be localized, it is necessary to assign the cause to the "surviving system" as a whole. Subsequent evidence may permit greater localization of the failure and permit reassignment of the cause to some "element." If failures which must be attributed to the "surviving system" occur frequently, it is probably a sign of inadequate failure investigation or an indication that the system is not developed sufficiently for a reliability improvement program.

The information derived from analysis of "element" failures in system tests can be used to serve two purposes. The first use is to indicate which "elements" show the poorest reliability in system testing. These "elements" then become candidates for redevelopment with priorities according to their statistical failure record. The second use of "element" failure data is to determine whether changes in design for reliability purposes are actually improvements. The reliability of redeveloped parts as "elements" in system tests is the best indication of the effectiveness of reliability improvement efforts.

Component Testing

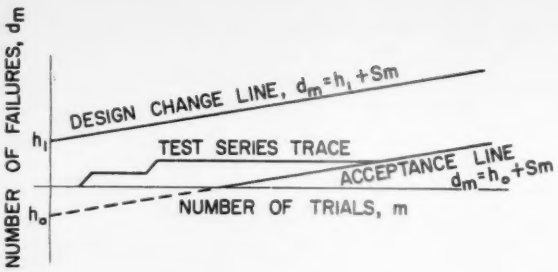
Parts which are selected for redevelopment because of their failure histories in system tests can usually be pretested on component test stands. The use of component testing permits inexpensive and rapid accumulation of a relatively large number of trials of newly redesigned parts. This procedure is desirable both for conservation of system test equipment and for obtaining statistically significant numbers of tests. However, the applicability of the results of component tests to system operation depends on the adequacy of stimulation of system conditions.

Each component in an operating system receives inputs from the system and delivers an output in the form of some type of performance. Component inputs must be simulated properly on a test stand in order to consider trials as valid representations of system operation. Sometimes it is very difficult to determine actual inputs and to provide reasonable simulation for component tests. An additional test stand requirement is component performance which simulates system operation.

The environment created by an operating system is frequently a factor in component operation. Simulation of this environment can sometimes be a critical factor in development of reliable components. Component failure criteria can vary widely depending on the detailed purposes of testing. Usually system improvement is served best by considering component tests successful only if similar operation in a system would have permitted successful system functioning.

Data Analysis

Statistical analysis of test data from a development program is complicated considerably by the continuous change in equipment under test. Considering tests



$$h_o = \text{ACCEPTANCE LINE INTERCEPT} = \frac{\text{LOG}\,\frac{\beta}{1-\alpha}}{\text{LOG}\,\frac{p_1}{p_o} - \text{LOG}\,\frac{1-p_1}{1-p_o}}$$

$$h_1 = \text{DESIGN CHANGE LINE INTERCEPT} = \frac{\text{LOG}\,\frac{1-\beta}{\alpha}}{\text{LOG}\,\frac{p_1}{p_o} - \text{LOG}\,\frac{1-p_1}{1-p_o}}$$

$$S = \text{SLOPE OF LINES} = \frac{\text{LOG}\,\frac{1-p_o}{1-p_1}}{\text{LOG}\,\frac{p_1}{p_o} - \text{LOG}\,\frac{1-p_1}{1-p_o}}$$

ACCEPTANCE INDICATES CONFIDENCE $1-\beta$ THAT RELIABILITY IS AT LEAST $1-p_1$ (LOWER RELIABILITY LIMIT)

DESIGN CHANGE REQUIREMENT INDICATES CONFIDENCE $1-\alpha$ THAT RELIABILITY IS LESS THAN $1-p_o$ (UPPER RELIABILITY LIMIT)

FIG. 1. Sequential analysis formulas.

in blocks requires an arbitrary selection of block size. Use of an accumulative record gives a reliability value influenced by early frequent failures. Weighting of accumulative data to suppress early records is once again arbitrary. It is proposed here to use a modified form of sequential analysis as a means for solving these problems. Background mathematics and nomenclature are from reference 1.

Sequential analysis does not require a fixed sample size for equipment acceptance test plans. It provides a simple graphical procedure for finding whether the tests which have been conducted are sufficient to reach desired statistical conclusions about the equipment under test. The analysis does not indicate equipment reliability but rather the probability that reliability is within specified boundaries. Fig. 1 shows the form of the test chart and the formulas for computing the boundary lines.

The difficulty with using normal sequential analysis in a development program is that the low reliability of early tests would indicate that equipment was unsatisfactory. In normal inspection procedures this would mean rejection. However, a development program is intended to improve inadequate equipment rather than reject it. An analysis procedure is required to show whether current equipment is satisfactory without regard to early test history.

The proposed solution to the problem of statistical evaluation of tests with changing reliability is to reverse the order in which tests are considered as compared with the usual sequential analysis. With this reversed sequential analysis, the most recent test result is plotted at the origin of the graphical test plan chart and each earlier test is plotted farther from the origin. Early test results are continuously displaced from later consideration and have a reduced influence on later decisions.

The use of reversed sequential analysis can be illustrated by an example. Suppose a test is required which offers 90 per cent confidence that equipment accepted has a reliability above a lower limit of 80 per cent. In order to establish a sequential test plan, it is necessary to specify an upper reliability limit as a criterion for rejection of unsatisfactory equipment. The level of the upper reliability limit influences the average number of trials which will be needed to reach a decision. This average sample number (ASN) varies with the reliability of the equipment under test. A formula from reference 1 for computing the ASN was selected to correspond to a reliability of one minus the slope of the sequential test boundary lines.

The choice of a value for the ASN in this type of program depends on the reliability level required and the amount of testing anticipated. A lower limit for the ASN is established by the number of trials without failure required for reliability demonstration. An upper limit is established by the necessity of keeping the ASN well below the total number of tests expected in the program. A good match between reliability requirements, program size, and sequential analysis parameters can usually be obtained by making the ASN about 3 times the number of trials without failure for demonstration and less than one tenth the number of tests anticipated in the program. In the example, an ASN of 29 was chosen. The formula in reference 1 may be used to obtain the corresponding upper reliability limit of 93.3 per cent at 90 per cent confidence.

Using the upper and lower reliability limits, a sequential test chart can be prepared as shown in Fig. 2. Upon completion of some specified number of trials, a record of number of failures versus number of trials is plotted on such a chart, starting with the most recent test. If the trace of such a plot does not cross either line, there is insufficient information to reach a decision. If the trace crosses the upper or design change line, the equipment is not satisfactory and a change must be made before further testing is permitted. If the trace crosses the lower or acceptance line, the equipment has passed the reliability acceptance requirements. If acceptance is not obtained, another attempt at acceptance can be made after completion of the specified number of new trials. Selection of the number of trials between acceptance attempts depends somewhat on objectives of individual programs, but a number of one-half the ASN appears to be reasonable in most cases.

Fig. 2 shows how a plot of test results might look at some point in a program. The trace (a) indicates that the equipment is not satisfactory and must be changed and tested further. Trace (b) indicates acceptable equipment reliability.

The same results may be obtained by two other types of presentation. Tabular representation of the acceptance and design change lines is sometimes convenient. Rapid graphical appreciation of a complete program can be obtained by a chart of failures versus trials starting with the earliest test at the origin. Reversed sequential analysis can be applied by using a transparent overlay with the acceptance and rejection lines on it. The origin of the overlay can be placed on each successive test result as it is plotted to test for acceptance or a change requirement. The latter method avoids repeated replotting of data which is required by the normal reversed chart.

Sequential analysis in the reversed form presented here lacks some of the statistical rigor of the original work. Using samples from a changing population means that acceptance is based on an average reliability over the most recent portion of the tests conducted. Sequential analysis is felt to be a useful, if not exact, tool for this purpose because equipment reliability is expected to change relatively slowly. The use of the rejection line to indicate a mandatory change rather than outright rejection has the effect of giving the equipment "another chance." This procedure actually reduces the producer's risk. However, the limited number of tests available for most practical programs prevents any appreciable probability of eventual acceptance of seriously deficient equipment. Work to date on the consequences of these statistical questions has indicated that they do not lead to serious errors, but further investigation is required.

In the conduct of a reliability development program, it is desirable to follow progress as indicated by test data. An interim reliability estimation method is needed for this purpose. Reversed sequential analysis can be used for this application. A chart can be prepared with a series of acceptance lines corresponding to a series of lower limits up to and including the acceptance value. The upper reliability limit corresponding to each lower limit is determined by the specification of ASN and confidence levels. The establishment of fixed confidence levels and ASN corresponds to the requirement:

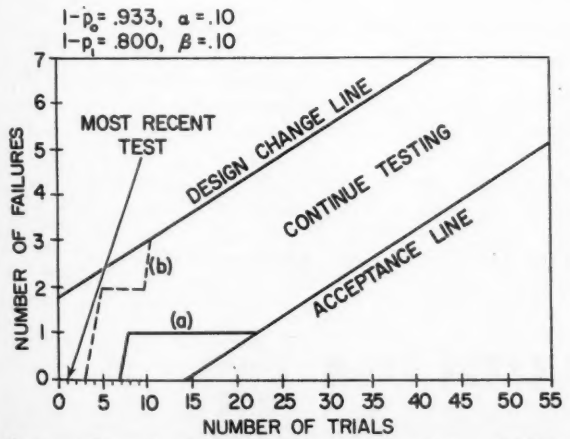

$1-p_0 = .933$, $\alpha = .10$
$1-p_1 = .800$, $\beta = .10$
MOST RECENT TEST
DESIGN CHANGE LINE
CONTINUE TESTING
ACCEPTANCE LINE
(b)
(a)
NUMBER OF FAILURES
NUMBER OF TRIALS
0 1 2 3 4 5 6 7
0 5 10 15 20 25 30 35 40 45 50 55

FIG. 2. Example of reversed sequential analysis reliability demonstration chart.

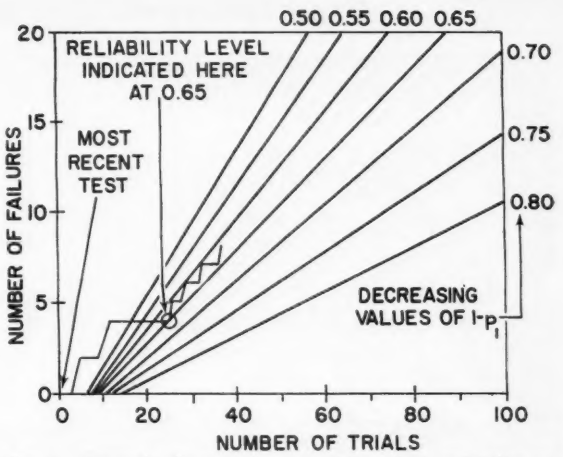


FIG. 3. Example of reversed sequential analysis reliability reporting chart.

$$[\log (p_1/p_0)] \{\log[(1 - p_0)/(1 - p_1)]\} = k \text{ (a constant determined by demonstration values of } p_0 \text{ and } p_1)$$

This equation can be solved for pairs of values of p_0 and p_1 by means of the following equation using a parametric variable x. Useful values for p_0 and p_1 are obtained with x between zero and one although the equation has solutions for all positive values of x.

$$p_0 = (e^{k/x} - 1)/(e^{x+(k/x)} - 1), \quad p_1 = e^x p_0$$

The series of acceptance lines obtained from pairs of p_0 and p_1 values forms a fan as shown in Fig. 3. The interim reliability value to be reported corresponds to the lowest acceptance line crossed by the trace of the test record from the latest reporting period. Design change lines are not used for interim reporting. Determination of interim reliability values at the end of monthly reporting periods instead of after a specified number of trials appears to be most convenient for administration of reliability programs.

This method for calculating interim reliability values is intended to form an integral part of a reliability development program. By following the progress of system reliability, the effectiveness of component improvements can be evaluated. As the program progresses, system reliability should approach the specified goal. The method of calculation used for reporting interim reliability will give results which converge toward the required level as reliability improves. When reliability finally reaches the acceptable value, the interim reporting procedure will automatically indicate that the reliability improvement program has reached its goal.

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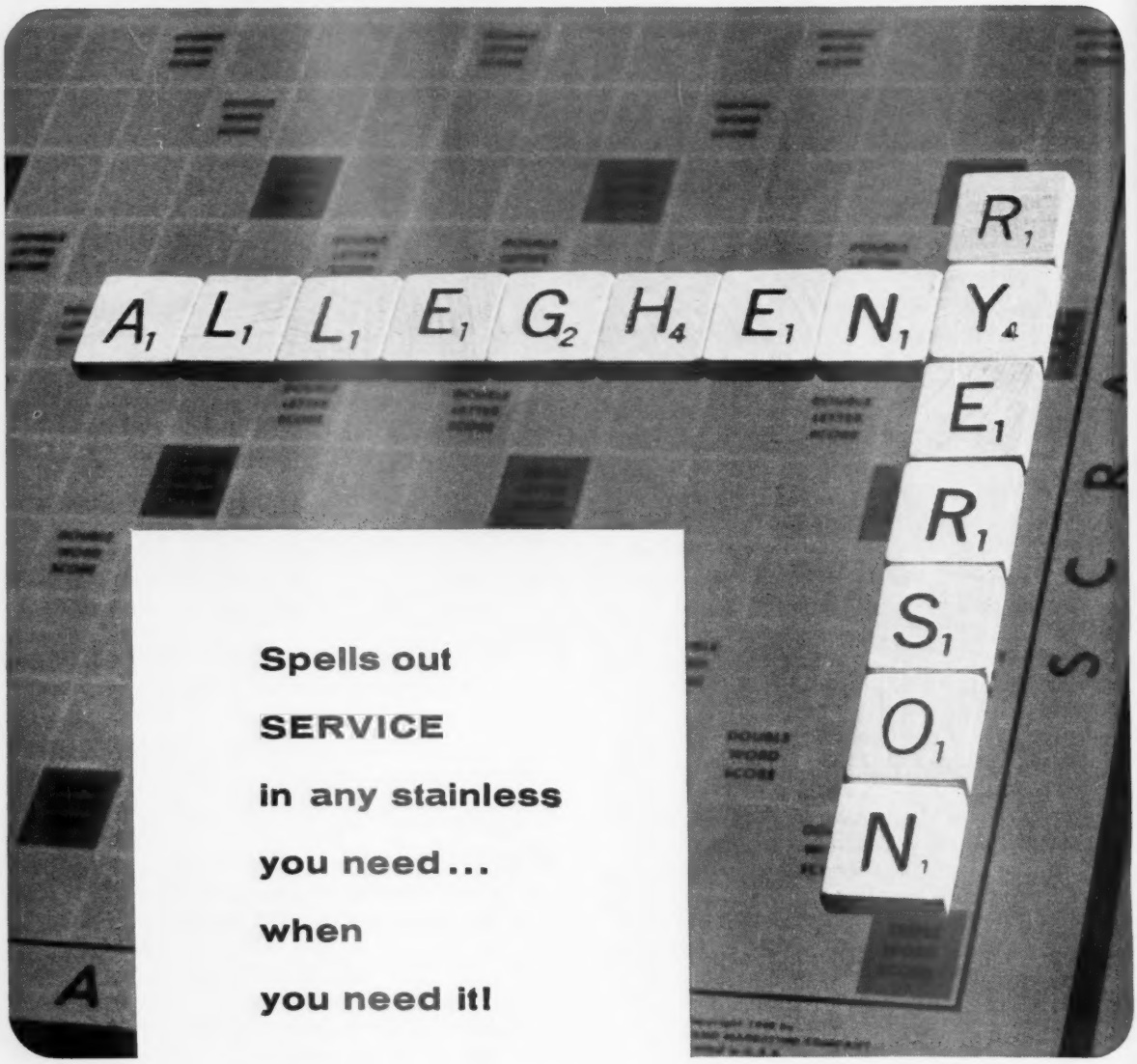

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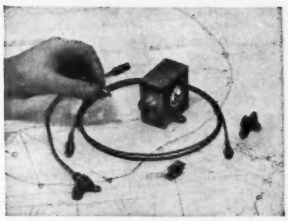

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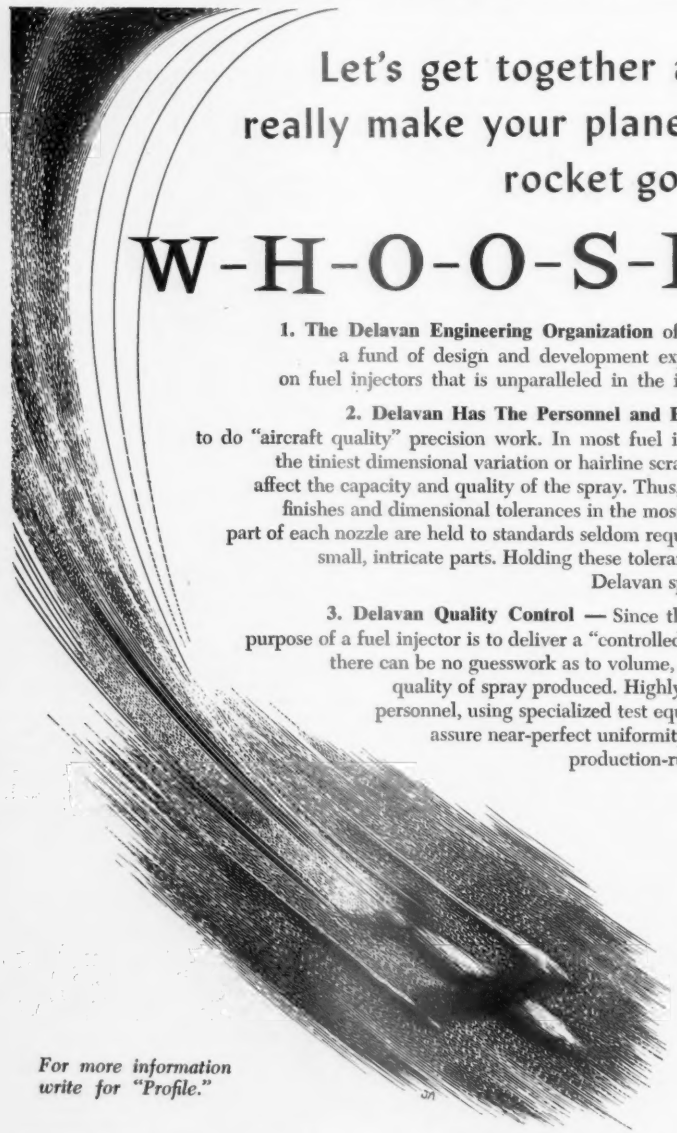

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ACOUSTICS, SOUND, NOISE

TURBOJET ENGINE NOISE REDUCTION WITH MIXING NOZZLE-EJECTOR COMBINATIONS. W. D. Coles, J. A. Mihaloew, and E. E. Callaghan. US, NACA TN 4317, Aug., 1958. 33 pp. 17 refs. Investigation of several noise suppressors consisting of combinations of mixing nozzles and injectors using two full-scale turbojet engines. The effects of ejector dimensions on noise suppression and engine performance are investigated. The ejector can restore the static thrust loss caused by the use of mixing nozzles or can provide static-thrust augmentation. The noise reduction obtained from an ejector is a function of the secondary airflow rate and results from the diffusion of the jet to lower velocity. Velocity profiles at the ejector exit are compared with previous results obtained on conical nozzles and with calculated free-jet boundaries resulting from normal spreading at equivalent downstream distances.

MESSUNG UND BEURTEILUNG DES STRAHLLÄRMS IN DER UMGEBUNG EINES BRENNKAMMERPRÜFSTANDES. O. Lutz, W. Alvermann, W. Dietze, and H. Dahlen. DFL Inst. Strahltriebwerke Bericht No. 85, May, 1958. 32 pp. In German. Measurement of jet noise in the vicinity of a combustion-chamber test rig. The location of the maximum noise intensity was found to be along a cone 45° from the jet axis. Results indicate that a fixed insulation combined with the test stand cannot be used due to the presence of some reaction effects.

AERODYNAMICS, FLUID MECHANICS

SEMINAIRE D'AEROTHERMIQUE DE LA FACULTE DES SCIENCES DE PARIS. I - CONVECTION TURBULENTE DANS UN CONDUIT DANS LE CAS D'UN FLUIDE DE NOMBRE DE PRANDTL ELEVE. G. Ribaud. II - QUELQUES RESULTATS D'EXPERIENCES SUR LA TURBULENCE - CORRELATIONS SPATIOTEMPORELLES. A. Favre. III - QUELQUES RECHERCHES AERODYNAMIQUES DU "ROYAL AIRCRAFT ESTABLISHMENT" SUR LES PROBLEMES CONCERNANT L'ECHAUFFEMENT AERODYNAMIQUE. R. J. Monaghan, J. F. W. Crane, and J. Picken. IV - EMPLOI DE LA STRIOSCOPIE INTERFERENTIELLE DANS L'ETUDE DES ECOULEMENTS AERODYNAMIQUES. Y. Latron. V - FONCTIONNEMENT D'UN BIPRISME DE WOLLASTON POUR L'INTERFEROMETRIE DIFFERENTIELLE EN LUMIERE POLARISEE. G. Gontier. VI - COUCHES LIMITES EN ECOULEMENT SUPERSONIQUE RALENTI - INTERACTION COUCHE LIMITE-ONDE DE CHOC. R. Michel. VII - REMARQUE SUR CERTAINS ECOULEMENTS FAIBLEMENT SUPERSONIQUES. G. Gontier and A. Martinot-Lagarde. VIII - UNE NOUVELLE METHODE DE MESURE DES COEFFICIENTS LOCAUX DE CONVECTION. H. Cordier. IX - LA CONVECTION FORCEE DE LA CHALEUR POUR DES FILS AUX TRES PETITS NOMBRES DE REYNOLDS. J. Gosse. X - UNE NOUVELLE METHODE DE MESURE DES TEMPERATURES UTILISANT LA THERMOSENSIBILITE DES FLUORESCENCES. P. Thureau. XI - COMPORTEMENT DES PRISES DE PRESSION D'ARRET EN COUCHE LIMITE TURBULENTE COMPRESSIBLE. M. Plan. XII - UTILISATION DES CALCULATRICES AUTOMATIQUES DANS LES CALCULS D'ADAPTATION D'ECHANGEURS THERMIQUES. R. Doussain. France, Min. de l'Air NT 73, 1958. 192 pp. 71 refs. SDIT, 2 Av. Porte-d'Issy, Paris 15, Frs. 2.730. In French. Compilation of twelve papers covering: development of velocity curves to calculate the turbulent convection in a duct for the case of a fluid with high Prandtl Number; results of turbulence measurements downstream of a grid and in the boundary layer over a flat plate, including space-time correlations and turbulence spectra; survey of RAE investigations covering problems of aerodynamic heating; basic principles of a method for flow visualization (interferential streak method), practical application, and experimental wind-tunnel results; working principle of a polarized light interferometer with Wollaston's biprism; survey of boundary-layer/shock-wave interaction phenomena in supersonic flow; application of shadowgraph technique to

the study of transonic flow over a half-profile; development of a new method for measuring local convection coefficients; results of investigations on forced heat convection using wires with very small Reynolds Numbers; development of a new method for temperature measurements using fluorescence thermosensitivity; evaluation of the design of stagnation pressure gages for compressible turbulent boundary layer studies; and application of electronic computers to the calculation of heat exchanger application.

Aerothermodynamics

EXACT SOLUTION OF LAMINAR HEAT TRANSFER IN WEDGE-SHAPED PASSAGES WITH VARIOUS BOUNDARY CONDITIONS. J. T. Yen. USAF WADC TR 57-224 [AD 118190], July, 1957. 42 pp. Analysis in which the various boundary conditions are taken respectively as constant peripheral wall heat flux, constant peripheral wall temperature, and arbitrary peripheral wall heat flux or temperature. All cases have the same axial boundary condition of constant heat flux. Results are presented for calculations of the distributions of the wall and fluid temperatures as well as of local and average heat transfer coefficients. Comparison is made with the corresponding parameters in a circular sector duct with peripherally constant wall temperature. A similarity analysis to find the parameters for heat transfer inside both the fluid and duct walls is included.

Boundary Layer

AN APPROXIMATION TO THE BOUNDARY LAYER FLOW ALONG AN EDGE. L. Sowerby. Quart. J. Mech. & Appl. Math., Aug., 1958, pp. 290-301. Analysis of the steady flow of viscous incompressible fluid past an infinite flat quarter plate, the main stream flow being parallel to one edge of the plate. Boundary layer equations are derived in a system of parabolic coordinates, and expansions in series provide a set of ordinary differential equations to determine the flow near this edge of the plate. An iterative procedure to solve these equations is described; the approximations thus obtained indicate a decrease from the normal flat-plate value in the thickness of the boundary layer at the edge, and there is a singularity in the density of the skin friction at the edge.

ON DISPLACEMENT THICKNESS. M. J. Lighthill. J. Fluid Mech., Aug., 1958, pp. 383-392. Presentation of four alternative theoretical treatments of displacement thickness, and analysis of the influence of boundary layers and wakes on the flow outside them, first for two-dimensional and then for three-dimensional laminar or turbulent incompressible flow. These theoretical treatments are called the methods of flow reduction, equivalent sources, velocity comparison, and mean vorticity.

ETUDE EXPERIMENTALE DE LA COUCHE LIMITE TURBULENTE ET DE SON INTERACTION AVEC L'ONDE DE CHOC SUR UN DEMI-PROFIL EN ECOULEMENT TRANSSONIQUE. R. Michel. France, ONERA NT 47, 1958. 22 pp. In French. Experimental investigation of the turbulent boundary layer over a circular profile in transonic flow for various positions of the shock wave. A marked increase in boundary-layer thickness is observed across and downstream of the shock wave. The displacement thickness at the leading edge increases up to 40% of the maximum profile half-thickness. The calculation of the momentum thickness is in good agreement with experiment across and downstream of the shock, but a discrepancy affecting the classic equations is found for the trailing edge. Includes description of the installation and experimental methods used.

EFFECTS OF FIXING TRANSITION ON THE TRANSONIC AERODYNAMIC CHARACTERISTICS OF A WING-BODY CONFIGURATION AT REYNOLDS NUMBERS FROM 2.4 TO 12 MILLION. L. W. Hunton. US, NACA TN 4279, July, 1958. 56 pp. Description of an investigation with a wing-body configuration having a plane tapered wing of aspect ratio 3 and 3%-thick biconvex section tested at Mach Numbers from 0.7 to 1.3 to determine the effects of fixing boundary-layer transition with wires. The analysis is based on lift, drag, and pitching-moment results obtained in the Ames 11 ft. transonic wind tunnel. Results indicate that with free transition of the boundary layer on the model, large effects of Reynolds Number occur on the aerodynamic characteristics near zero lift. These effects disappear at test Reynolds Numbers of approximately 8 million and above. Fixing of transition on the model practically eliminates these effects over the entire Reynolds Number range investigated. Furthermore, the fixed transition data match closely the results obtained with free transition at a Reynolds Number of 12 million. The wires used to trip the boundary layer cause an increment in drag coefficient of about 0.0008 at a Reynolds Number of 12 million which remains approximately constant throughout the Mach Number range.

A SOLUTION OF THE NAVIER-STOKES EQUATIONS ILLUSTRATING THE RESPONSE OF A LAMINAR BOUNDARY LAYER TO A GIVEN CHANGE IN THE EXTERNAL STREAM VELOCITY. J. Watson. Quart. J. Mech. & Appl. Math., Aug., 1958, pp. 302-325. Derivation of exact solutions of the Navier-Stokes equations by a Laplace transform technique for two-dimensional, incompressible flow past an infinite plane porous wall. The flow is assumed to be independent of the distance parallel to the wall and the velocity component normal to wall constant. A general formula for the velocity distribution is derived as a function of the given free-stream velocity; general formulas for the skin friction and displacement thickness are obtained. Several particular cases of flow are considered and the respective results given.

AN EXAMPLE OF UNSTEADY LAMINAR BOUNDARY LAYER FLOW. Appendix - NUMERICAL INTEGRATION OF DIFFERENTIAL EQUATIONS. Itiro Tani. Tokyo U., Aero. Res. Inst. Rep. 331, June, 1958. 42 pp. Analysis of the flow in a two-dimensional incompressible laminar bound-

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ary layer with a time-dependent pressure gradient. The pressure gradient is considered to vary with time in a specified manner so that the three independent variables - time and space coordinates - are grouped together into two. A solution is obtained in the form of a power series, six of whose coefficients are obtained by integrating the differential equations. However, the series converges so slowly that the coefficients obtained are not sufficient, and an approximate method of continuation is required to carry out the solution to a point of separation. The solution of the problem may be interpreted to provide some information on the unsteady flow associated with a diffusor or an airfoil in which the angle of divergence or angle of attack vary with time.

AN UNSTEADY TURBULENT BOUNDARY LAYER. S. K. F. Karlsson. Johns Hopkins U., Dept. Aero. Rep., May, 1958. 79 pp. Investigation of the turbulent boundary layer developing on a flat plate with a parallel flow whose velocity fluctuates sinusoidally in magnitude about a constant mean. Hot-wire measuring techniques are used to study the response of the layer at Reynolds Number of 3.6×10^3 for fluctuation amplitudes up to $\pm$ 34% of the free stream velocity. Measurements are made of mean velocity, amplitudes of in and out of phase components of the first harmonic of the periodic fluctuations, and the intensity of higher harmonics and turbulence. It is found that nonlinear effects, even at the largest fluctuation amplitudes, were so small that they were obscured by experimental errors.

AN EXPERIMENTAL STUDY OF THE TURBULENT BOUNDARY LAYER BEHIND THE INITIAL SHOCK WAVE IN A SHOCK TUBE. W. A. Martin. J. Aero/Space Sci., Oct., 1958, pp. 644-652. 24 refs. Experimental study of the shock tube boundary layer between the initial shock wave and the contact region for shock pressure ratios P_{21} of 2.75 and 8.0 with a corresponding Reynolds Number range of 0-50 x 16^6 and 0-100 x 10^6, respectively. The study was carried out in the UTIA 2 x 7 in. shock tube using a 9 in. field Mach-Zehnder interferometer to obtain boundary-layer density profiles. Shadowgraph, schlieren and interferogram photographs and thin-film thermometer measurements indicate that the region was almost completely occupied by turbulent boundary layer. Experimental density profiles and boundary-layer thickness measurements are presented together with calculated temperature and velocity profiles, displacement and momentum thicknesses, and local skin friction. Experimental results obtained compare favorably with the theory of Mirels. The velocity profiles at higher Reynolds Number for $P_{21} = 2.75$ follow a 1/5 power law closer than the 1/7 power law. For $P_{21} = 8$ all the experimental profiles are a 1/5 power.

Flow of Fluids

THREE-DIMENSIONAL STEADY, RADIAL FLOW OF VISCOUS, HEAT-CONDUCTING, COMPRESSIBLE FLUID. Akira Sakurai. Quart. J. Mech. & Appl. Math., Aug., 1958, pp. 274-289. Solution of the Navier-Stokes equations in the case of steady, three-dimensional, radial flow of source and sink types, taking into account the effects of compressibility, viscosity, and heat conduction. The problem of finding the deviation from the inviscid solution due to the effects of viscosity and heat conduction is stressed. The fundamental equations are reduced to a single second-order differential equation of the singular perturbation type, which is similar to the corresponding equation obtained in the case of two-dimensional radial flow. The solutions containing shock waves are studied in detail.

THE STABILITY OF VISCOUS FLOW BETWEEN ROTATING CYLINDERS. S. Chandrasekhar. Royal Soc. (London) Proc., Ser. A, Aug. 19, 1958, pp. 301-311. 10 refs. USAF-supported presentation of a method for solving the exact characteristic value problem of hydrodynamic stability of viscous flow between rotating cylinders. Detailed numerical results are obtained for the case when the ratio of radii of the two cylinders is one-half.

EXPERIMENTS ON THE STABILITY OF VISCOUS FLOW BETWEEN ROTATING CYLINDERS. I - TORQUE MEASUREMENTS. R. J. Donnelly. Royal Soc. (London) Proc., Ser. A, Aug. 19, 1958, pp. 312-325. 10 refs. Measurements of the hydrodynamic stability of viscous flow between concentric cylinders using a small rotating cylinder viscometer. The inner cylinder is rotated and the outer cylinder is freely suspended on a torsion fiber. The onset of instability is characterized by a discontinuity in the measured effective viscosity. Results for the case of a small annular gap between cylinders agree to within 1.3% with the theory for an infinitesimal gap. The results for the case of a wide annular gap agree to within 0.5% with the exact theory given by Chandrasekhar. Detailed measurements of the torque above the onset of instability are given in both cases.

INVISCID HYPERSONIC FLOW AROUND SPHERES AND CIRCULAR CYLINDERS. E. D. Martin. Rensselaer Polytech. Inst. Dept. Aero. Eng. TR AE5807 (AFOSR TN 58-448) [AD158254], Apr., 1958. 70 pp. 19 refs. Description of the pattern and properties of the fluid flow around the nose region of a blunt body moving at steady hypersonic speed through a gas which may be treated as a continuous fluid. An approximate method for calculating such flow is presented; results, in terms of simple closed form analytical expressions, are given. The equations of motion are integrated, and a third order ordinary differential equation is obtained. For the sphere the solution is a polynomial, while the two-dimensional solution is formed in terms of Bessel functions. Some important flow properties found from this solution are: shock detachment distance, velocity, stagnation point velocity gradient, vorticity, stream function, and pressure coefficient. The results are given in terms of the shock density ratio and are found to agree fairly well with those obtained in other theoretical and experimental investigations, the results for the sphere being more accurate than those for the circular cylinder.

THE BOUNDARY-LAYER EQUATION FOR AXIALLY SYMMETRIC FLOW PAST A BODY OF REVOLUTION - MOTION OF A SPHERE. David Meksyn. J. Aero/Space Sci., Oct., 1958, pp. 631-664. Derivation of the boundary-layer equation for axially symmetric flow past a body of revolution by using a procedure which transforms the usual boundary-layer equations for axially symmetric flow to those of a plane flow. This method is applied to find the friction and the separation point for a flow past a sphere. The equation is integrated asymptotically by the method developed for plane flow, where the partial differential equation is reduced to an ordinary equation. A short straightforward method of step-by-step integration is used. The procedure for determining the separation point is given.

PRESSURE DISTRIBUTIONS AT TRANSONIC SPEEDS FOR SLENDER BODIES HAVING VARIOUS AXIAL LOCATIONS OF MAXIMUM DIAMETER. J. B. McDevitt and R. A. Taylor. US, NACA TN 4280, July, 1958. 112 pp. Presentation of the measured static-pressure distributions at the model surfaces and in the surrounding flow field for a related series of bodies of revolution having locations of maximum cross-sectional areas at 0.3, 0.4, 0.5, 0.6, and 0.7 of the body length. The data were obtained with the various bodies, all of fineness ratio 12, at zero angle of attack. The Mach Number varied from 0.80 to 1.20, and the Reynolds Number, based on body length, from approximately 23.4×10^6 to 24.6×10^6.

CONDITIONS GOVERNING THE INITIAL SLOPE OF A SONIC LINE ON A BLUNT BODY. A. G. Hammitt and J. J. Sullivan. Princeton U. Dept. Aero. Eng. Rep. 408 (USAF WADC TN 58-73) [AD 151066], Feb., 1958. 10 pp. Study showing that the conditions for an initially normal sonic line can be derived for general shapes by an elementary consideration of flow relations and that an approximate initial slope of the sonic line can be calculated for certain simple body shapes. These conditions depend upon the shock shape of the nose and the body radius of curvature. For a plane body, the sonic line forms an acute angle with the body, which is relatively independent of Mach Number. For axially symmetric bodies, the angle may be either acute or obtuse, depending on the local radius of curvature, the free stream Mach Number, and other parameters.

VLIIANIE MALOGO ZATUPLENIIA PEREDNEGO KONTSA TELA NA EGO OBTEKANIE POTOKOM S BOL'SHOI SVERKHZVUKOVOI SKOROST'IU. G. G. Chernyi. AN SSSR Otd. Tekh. Nauk Izv., Apr., 1958, pp. 54-66. 23 refs. In Russian. Investigation of the effect of slight nose bluntness on the hypersonic flow around a body. Includes tentative extension of the hypersonic flow theory past bodies with sharp leading edges. The size of the bluntness is ignored in the case of flow in an area comparable to the length of the body. The bluntness effect is considered in the form of concentrated forces acting from the leading edge direction, and Newton's formula is used for the approximation at hypersonic speeds. The investigation is restricted to the case of a symmetrical flow past airfoils or bodies of revolution. A numerical approach is used for flow around a plate with blunt leading edge, a circular cylinder at incidence, a thin blunt wedge, and a thin blunt cone.

OBTEKANIE SIMMETRICHNOGO PROFILIA S OTOSHEDSHEI UDARNOI VOLNOI. O. M. Belotserkovskii. Prikl. Mat. i Mekh., Mar.-Apr., 1958, pp. 206-219. 11 refs. In Russian. Survey of previous investigations and evaluation of various approaches used for the calculation of flow past a symmetrical profile with shock wave separation. Includes derivation of a numerical solution by means of the method of integral relationships, reducing the integration of the system of nonlinear differential equations with partial derivatives to the numerical solution of a certain approximating system of ordinary differential equations. The use of electronic computers leads to final results with the required degree of accuracy for the specific problem. Few illustrative cases presented include a flat profile with the axis of symmetry and a circular cylinder at varying Mach Numbers. Formulas for the flow behind the shock wave are derived and an analysis of the theoretical calculations is presented along with a comparison to experiment. Results of the calculation are used to compute the pressure pattern over the body and around it, the sonic line, the characteristics, and other parameters. An analogous procedure is used to calculate the flow around an axisymmetrical body with shock wave separation.

HEAT-TRANSFER AND PRESSURE MEASUREMENTS ON FLAT-FACED CYLINDERS AT A MACH NUMBER OF 2. Appendix A - VARIATION OF MEASURED QUANTITIES WITH TIME. Appendix B - PRESSURES MEASURED ON 12-INCH MODEL. Appendix C - THEORETICAL HEAT-TRANSFER DISTRIBUTIONS. W. E. Stoney, Jr., and J. T. Markley. US, NACA TN 4300, July, 1958. 38 pp. 13 refs. Description of tests on cylinders of 12-in. and 4-in.-diameter under sea-level conditions in the preflight jet of the Langley Pilotless Aircraft Research Station. Both pressure distributions and heat-transfer rates were measured. The pressure data from the 4-in.-diameter model agree well with previously obtained results. The stagnation-point pressure gradient is of about 30% of the gradient on an equivalent-size hemisphere. The heat-transfer data agree reasonably well with the theoretical results when the flow is laminar. The stagnation-point heating rates are approximately 55% as great as the stagnation heating rates on a hemisphere of equal diameter.

ETUDE EXPERIMENTALE D'UN FUSELAGE EN SUPERSONIQUE ELEVE. R. Cérésuela. La Recherche Aéronautique, May-June, 1958, pp. 3-11. In French. Experimental investigation in a supersonic wind tunnel at Mach Numbers up to 4.3 and Reynolds Numbers of 9×10^6 on double-taper bodies of revolution as part of a study covering the aerodynamic characteristics of fuselage and wing-body combinations. Measurements of lift

and frictional and induced drag are compared with theoretical values. A description of the experimental installation and methods used is also given. Results indicate that the theory does not cover several important effects of the fuselage in supersonic flow, such as lift augmentation and adverse effect on stability.

AN ESTIMATE OF THE FLUCTUATING SURFACE PRESSURES ENCOUNTERED IN THE REENTRY OF A BALLISTIC MISSILE. Appendix A - ALTITUDE AT WHICH MAXIMUM LOCAL DYNAMIC PRESSURE IS ENCOUNTERED, Appendix B - REYNOLDS NUMBER PER FOOT BASED ON CONDITIONS IMMEDIATELY BEHIND SHOCK AT NOSE ($\rho_1 V_1/\mu_1$) CORRESPONDING TO MAXIMUM LOCAL DYNAMIC PRESSURE. Appendix C - CALCULATION OF TIME DURING WHICH HIGH VALUES OF LOCAL DYNAMIC PRESSURE ARE ENCOUNTERED. E. E. Callaghan. US, NACA TN 4315, July, 1958. 18 pp. Calculation of the magnitude of the surface sound pressure levels occurring on blunt-nosed vehicles during reentry into the earth's atmosphere. The results presented cover a wide range of reentrance velocities and angles, as well as sizes and weights of the vehicle. The analysis is based on current subsonic results which can be extrapolated to high supersonic speeds for a blunt-nosed body, due to the low values of local Mach Number behind the shock but outside the boundary layer. The analysis is limited to the particular point on the body where the maximum local sound pressure level is obtained. A constant value of the ratio of the surface root-mean-square pressure to the local dynamic pressure, which is based on current subsonic data, is assumed. The results indicate that surface sound pressure levels of the order of 150 db. or higher are likely to be encountered. The time of exposure to these levels is found to be of the order of 25 seconds.

A NOTE ON THE DRAG OF WING-BODY COMBINATIONS IN LINEARISED SUPERSONIC FLOW. L. E. Fraenkel. Aero. Quart., Aug., 1958, pp. 305-312. Modification of Ward's area-transfer rule to make it more suitable for configurations with fuselages or nacelles which are neither slender nor smooth (although they are assumed to have small profile slope). The body source strength of Ward's analysis, which is appropriate only for smooth, slender bodies, is replaced by a source strength which is valid more generally. However, the drag contributions of the body multi-sources and of the interference field are still neglected, so that the theory is tentative rather than rigorous.

FIRST-ORDER APPROACH TO A STRONG INTERACTION PROBLEM IN HYPERSONIC FLOW OVER AN INSULATED FLAT PLATE. Hakuro Oguchi. Tokyo U., Aero. Res. Inst. Rep. 330, June, 1958. 30 pp. 16 refs. Analysis of the strong interaction phenomenon over an insulated semi-infinite flat plate with a sharp leading edge. The consistent treatment in which the boundary-layer solution may be joined continuously with the inviscid solution regarding flow variables including pressure, normal velocity, temperature, and density is stressed. It is shown that the behavior of the inviscid solution may be consistent with that of the boundary layer to at least first-order approximation. The first-order boundary-layer problem is formulated; calculations are carried out for the cases of air and helium. It is found that the region in which the viscous effect plays a significant role ranges from zero to a certain finite value of the similarity coordinate η in the corresponding incompressible boundary layer. The numerical results indicate that the induced pressure is considerably smaller than the estimate of Lees. Present results and experimental data obtained in helium by Erickson show excellent agreement.

TWO-DIMENSIONAL INCOMPRESSIBLE MAGNETOHYDRODYNAMIC FLOW ACROSS AN ELLIPTICAL SOLENOID. N. H. Kemp and H. E. Petschek. Avco Res. Lab. RR 26, Apr., 1958. 66 pp. USAF-supported analysis of a constant-conductivity fluid through an elliptically-shaped solenoid containing a constant magnetic field directed normal to the flow plane. The effect of both Hall current and ion slip has been included in the Ohm law used for the fluid. The analysis is performed by means of a perturbation method in two parameters, one being the magnetic Reynolds Number R_m and the other the ratio of magnetic force per unit area to dynamic pressure S. Calculations are carried through first order in each parameter, and closed-form analytic expressions are obtained for the force and moment on the solenoid, the current density, stream function, magnetic field, and other pertinent physical quantities.

MAGNETO-GASDYNAMICS OF HYPERSONIC COUETTE FLOW. Z. O. Bleviss. (Douglas Rep. SM-23098, Feb., 1958.) J. Aero/Space Sci., Oct., 1958, pp. 601-615. 18 refs. Investigation of the Couette flow problem extended to include a uniform externally imposed magnetic field normal to the walls. Numerical solutions are presented for air for the case of the insulated wall for Mach Numbers from 10 to 30, and for the case of heat transfer from Mach Numbers of 20 and 30. The effects of the magnetic field are shown upon the velocity, temperature, electrical current density, and induced magnetic field distributions, and upon the skin friction, heat transfer, and total drag. Results indicate that relatively weak magnetic fields produce large increases in the total drag, large reductions in the skin friction, and relatively little effect on the heat transfer. Whereas the total drag without magnetic field is skin friction drag, the drag with magnetic field is primarily magnetic drag.

NON-EQUILIBRIUM FLOW OF AN IDEAL DISSOCIATING GAS. N. C. Freeman. J. Fluid Mech., Aug., 1958, pp. 407-425. Extension of the theory of an ideal dissociating gas developed by Lighthill for conditions of thermodynamic equilibrium to nonequilibrium conditions by postulating a simple rate equation for the dissociation process which includes the effects of recombination. This equation contains the equilibrium parameters of the Lighthill theory plus a further nonequilibrium pa-

rameter which determines the time scale of the dissociation phenomena. The behavior of this gas is investigated in flow through a strong normal shock wave and past a bluff body. The assumption is made that the gas receives complete excitation of its rotational and vibrational degrees of freedom in an infinitesimally thin region according to the familiar Rankine-Hugoniot shock wave relations before dissociation begins. The variation of the relevant thermodynamic variables downstream of this region is then computed for particular cases.

INTRODUZIONE ALLO STUDIO DELL'AEROTERMOCHIMICA. L. G. Napolitano. L'Aerotecnica, Apr., 1958, pp. 96-108. 18 refs. In Italian. Analysis of the basic equations of aerothermochemistry with the assumption that the effects due to chemical reactions and to macroscopic convective motion are of the same order of magnitude. Three specified forms of these equations are derived. By furthering the analysis of steady nondimensional motions it is shown that: (a) the stagnation enthalpy of the mixture is constant along a streamline; (b) Bernoulli equation and Crocco theorem still hold; (c) the function $S_t = S + \int \frac{\rho_i \sigma_i e}{T}$, where S is the total specific entropy, is constant along a streamline. The characteristic equations and the corresponding regularity conditions are derived for the general case of steady, two-dimensional, rotational motion of a reacting binary gas mixture. The results yielded by an investigation of the dissipative motion of a reacting binary gas mixture are given.

BOUNDARY-LAYER STABILITY DIAGRAMS FOR ELECTRICALLY CONDUCTING FLUIDS IN THE PRESENCE OF A MAGNETIC FIELD. V. J. Rossow. US, NACA TN 4282, Aug., 1958. 32 pp. 18 refs. Study of the effectiveness of a magnetic field in stabilizing the laminar flow of an incompressible, electrically conducting fluid. The neutral stability curves pertaining to a two-dimensional sinusoidal disturbance are presented for flow over a semi-infinite flat plate in the presence of either a coplanar or a transverse magnetic field. It is found that the magnetic field stabilizes the flow unless the velocity profile is distorted by the magnetic field to an inherently unstable shape. This occurs when a transverse magnetic field is fixed relative to a semi-infinite flat plate.

THE EQUILIBRIUM OF A SELF-GRAVITATING INCOMPRESSIBLE FLUID SPHERE WITH MAGNETIC FIELD. P. L. Bhatnagar. Indian Inst. Sci. J., Sect. A, Apr., 1958, pp. 50-73. 11 refs. Study of the magnetic fields which can prevail in an axisymmetric configuration in a coherent manner. Certain types of fields discussed include force-free, poloidal, toroidal, and combinations of the toroidal and poloidal fields. Equilibrium configurations and the total change in the magnetic energy are calculated for the toroidal field.

A REVIEW OF THE THERMODYNAMIC, TRANSPORT, AND CHEMICAL REACTION RATE PROPERTIES OF HIGH-TEMPERATURE AIR. C. F. Hansen and S. P. Heims. US, NACA TN 4359, July, 1958. 33 pp. 26 refs. Derivation of semi-empirical analytical expressions and presentation of examples illustrating the use of thermodynamic and transport properties of air to evaluate (a) equilibrium conditions following shock waves, (b) stagnation region heat flux to a blunt high-speed body, and (c) some chemical relaxation lengths in stagnation region flow. Includes discussion of the actual state of scientific knowledge and presentation of experimental results.

LAMINAR HEAT TRANSFER AROUND BLUNT BODIES IN DISSOCIATED AIR. N. H. Kemp, P. H. Rose, and R. W. Detra. Avco Res. Lab. RR 15, May, 1958. 36 pp. 12 refs. USAF-sponsored presentation of a method for calculating heat transfer based on an exact numerical solution of the boundary layer differential equations which result from a "local similarity" assumption. The solutions are correlated in terms of the external pressure gradient parameter β and a variable ratio of $\rho\mu$. Lewis Number effects are also discussed. This is accomplished numerically by an extension of the method which Fay and Riddell used at the stagnation point. The solutions, which depend on the local external flow conditions, vary around the body in contrast to the constant values used by Lees. The study is restricted to bodies of revolution at zero angle of incidence. Comparison is made with shock tube experiment on a hemisphere cylinder and on a flat-nosed cylinder.

STUDY OF SOME SUPERSONIC ROTATIONAL FLOW PROBLEMS BY A PERTURBATION TECHNIQUE. C. Thyagarajan and K. T. Yen. Rensselaer Polytech. Inst. Dept. Aero. Eng. TR AE5803 (AFOSR TN 58-624) [AD 162154], Apr., 1958. 27 pp. Analysis of some supersonic rotational inviscid flows by application of a small perturbation technique which uses generalized coordinates formed by streamlines and their orthogonal trajectories. With a properly prescribed pressure distribution on a body surface in generalized coordinates, the body shape and the pressure field in the physical plane can be determined. Using a conveniently chosen initial Mach Number distribution two examples are studied. The first one is concerned with a linear surface pressure distribution which gives a nearly wedge-shaped body in the physical plane. In the second case, to examine the phase shift of the pressure distribution for a supersonic rotational flow over a periodically wavy wall, a sinusoidal pressure distribution is chosen.

ON THE PROPAGATION OF SHOCK WAVES THROUGH REGIONS OF NON-UNIFORM AREA OR FLOW. G. B. Whitham. J. Fluid Mech., Aug., 1958, pp. 337-360. 14 refs. ONR-sponsored study of the work of Moeckel on the interaction of an oblique shock wave with a shear layer in steady supersonic flow and the work of Chester and Chisnell on the propagation of a shock wave down a nonuniform tube. It is shown that their basic results can be obtained by the application of the following rule: the relevant equations of motion are first written in characteristic form, then the rule is to apply the differential relation which must be satisfied by the flow quantities along a

characteristic to the flow quantities just behind the shock wave. Together with the shock relations this rule determines the motion of the shock wave. Some applications are made to such problem as converging and spherical shocks, propagation through a stratified layer, converging cylindrical shock waves in magnetohydrodynamics, shear layers in supersonic flow, an axisymmetric duct in supersonic flow, and propagation of bores in shallow water.

ON THE ACCURACY OF THE REPRESENTATION OF A LIFTING LINE BY A FINITE SET OF HORSESHOE VORTICES. A. R. Collar. Aero. Quart., Aug., 1958, pp. 232-250. Study of the error involved when the continuous distribution of lift on an unswept lifting surface is represented by a number of horseshoe vortices, the strengths of which are determined by a prescribed downwash. Attention is directed mainly to the case of elliptic loading, but an antisymmetric case is also studied to ensure that the conclusions are not peculiar to the elliptic case. If the number of vortices is m, it is concluded that, when the downwash at the center of each horseshoe vortex is prescribed equal to that for the continuous case, the total load due to the horseshoe system over-estimates the true load in the ratio $(m+1)/m$. If the circulation is determined for a wing of finite aspect ratio by its geometric incidence, the error will be less than that in the previous case; a correction formula involving m and the aspect ratio A is derived for this case.

RELAXATION TIME FOR REACTIONS BEHIND SHOCK WAVES AND SHOCK WAVE PROFILES. R. E. Duff. Phys. Fluids, May-June, 1958, pp. 242-245. Development of a relation between the reaction rate constants and the relaxation time for the approach to equilibrium of a chemical reaction behind a shock wave. The importance of the variation of temperature behind a shock on the rate of approach to equilibrium is shown. Numerical calculations of the shock wave profile in O_2 for two different dissociation mechanisms show that the relaxation time analysis is only appropriate for the description of the dissociation within a few per cent of equilibrium. The calculations also show that ozone is not an effective intermediate for the shock dissociation of O_2, and that it is impossible to define a relaxation time for the over-all dissociation process which is inversely proportional to pressure or density.

INFLUENCE OF SOLID-BODY ROTATION ON SCREEN-PRODUCED TURBULENCE. Appendix A - METHOD OF MEASUREMENTS. S. C. Traugott. Appendix B - MOTION OF A PERTURBED ELEMENT IN A ROTATING FLUID. Hsuan Yeh. US, NACA TN 4135, Aug., 1958. 100 pp. 28 refs. Investigation covering measurements of the radial distributions of the three components of turbulence intensity and the three turbulent shear stresses at a fixed distance downstream of the screen both with and without rotation. An energy balance is made for the three intensities from measured decay and dissipation terms. A peripheral velocity distribution like that of a rotating solid body imposed on the turbulence produced by screens is found to undergo very little change with distance along the axis of rotation. Measurements of the turbulent shear correlation between radial and peripheral fluctuations 17.5 mesh lengths from the farthest downstream screen give a small positive value for this quantity over the major position of the flow field. The other shear correlations are found to vanish. It is believed that the nonvanishing of this shear correlation is due to the fact that the flow is not fully developed, although the exact mechanism is not clear. Consideration of the qualitative nature of the turbulent shear stresses, based on the production term in the equations for these stresses, leads to results in agreement with the experimental findings. Such considerations also lead to results in agreement with experiments for the influence of curvature on a fully developed channel flow.

AN APPLICATION OF THE WEBER-ORR TRANSFORM TO THE PROBLEM OF TRANSONIC FLOW PAST A FINITE WEDGE IN A CHANNEL. J. B. Helliwell. Cambridge Philos. Soc. Proc., July, 1958, pp. 391-395. AFOSR-sponsored study of the flow pattern under the conditions proposed by Mackie and Pack. Includes derivation of an equation incorporating the physical details of the conservation of mass flow from which the downstream Mach Number may be deduced in terms of the upstream Mach Number and the channel width.

TURBULENCE AND TEMPERATURE FLUCTUATIONS BEHIND A HEATED GRID. Appendix - EFFECT OF HOT-WIRE NONLINEARITY ON TRIPLE CORRELATION MEASUREMENT. R. R. Mills, Jr., A. L. Kistler, V. O'Brien, and S. Corrsin. US, NACA TN 4288, Aug., 1958. 67 pp. 17 refs. Presentation of measurements made of fluctuation levels and various double and triple correlation functions in the approximately isotropic velocity and temperature fluctuation fields behind a hot grid. The double and triple correlation coefficient functions are of roughly the same spatial extent for the vector and scalar fields. As anticipated from theoretical considerations, the temperature fluctuations die out more slowly than does the turbulence.

Internal Flow

STALL PROPAGATION IN A CASCADE OF AIRFOILS. A. R. Kriebel, B. S. Seidel, and R. G. Schwind. US, NACA TN 4134, June, 1958. 122 pp. 19 refs. Experimental investigation of stall propagation in a stationary circular cascade in which high-speed schlieren and interferometer photography are used. The investigation suggests an analytical approach to the study of stall propagation which is valid only for an isolated blade row in an infinite flow field, but which is not restricted to small unsteady perturbations or to an assumed simplified cascade geometry. Conditions necessary for the existence of the assumed type of stall cells are described and equations are derived for the velocity of stall-cell propagation. The propagation velocities predicted for the theoretical potential

model correlate with all the experimental values measured in an isolated rotor within 15%.

ANALYTICAL RELATION FOR WAKE MOMENTUM THICKNESS AND DIFFUSION RATIO FOR LOW-SPEED COMPRESSOR CASCADE BLADES. Seymour Lieblein. US, NACA TN 4318, Aug., 1958. 31 pp. 15 refs. Derivation of a simple equation relating wake momentum thickness and suction surface diffusion ratio (ratio of maximum surface velocity to outlet velocity) of conventional low-speed cascade blades using a simplified boundary-layer theory in conjunction with several empirical constants. An analytical relation is thus obtained that describes the experimental correlations between momentum thickness and diffusion correlations previously reported.

SOME EFFECTS OF VANES AND OF TURBULENCE IN TWO-DIMENSIONAL WIDE-ANGLE SUBSONIC DIFFUSERS. Appendix A - DEFINITION AND DERIVATION OF ENERGY PARAMETERS AND THEIR COMPARISON WITH PRESSURE PARAMETERS. Appendix B - EFFECT OF EXIT-VELOCITY-PROFILE SQUARENESS ON PRESSURE RECOVERY AND PRESSURE EFFECTIVENESS. Appendix C - ACCURACY. C. A. Moore, Jr., and S. J. Kline. US, NACA TN 4080, June, 1958. 139 pp. 26 refs. Study of the flow mechanism using dye injection in a water table. The four regimes of flow found are expressed in terms of three parameters: (a) divergence angle, (b) ratio of throat width to wall length, and (c) free-stream turbulence. Also data are presented which demonstrate means for producing efficient diffusers for total included angles up to al least 45° by use of simple, short, flat vanes.

KINETIC THEORY OF LINEAR SHEAR FLOW. E. P. Gross and S. Ziering. Phys. Fluids, May-June, 1958, pp. 215-224. Study of the flow of a monatomic gas between two parallel plates kept at the same temperature and moving in opposite directions. Adopted are the customary boundary conditions in which a fraction of the molecules is specularly reflected and the rest emitted with a Maxwellian distribution characteristic of the plate. The space functions are determined by taking half-range velocity moments of the Boltzmann equation. Explicit results for the distribution function, flow velocity, and stress are given for a general law of force. Numerical results are worked out for hard sphere molecules. The method treats both microscopic boundary conditions and conservation laws. Precise results are obtained both for the low-pressure region and for the high-pressure coefficient of viscosity; the region of slip flow is analyzed. In this region of pressures, the deviations from the velocity profile of the hydrodynamic slip flow theory are everywhere very small, and are completely negligible at distances greater than 1/8 of a mean free path from a plate.

NONLINEAR OSCILLATIONS OF A COLUMN OF GAS. R. Betchov. Phys. Fluids, May-June, 1958, pp. 205-212. Theoretical analysis, based on discontinuous linearized solutions and a secular equation, of the motion of a column of air in a long pipe closed at one end and driven at the other by an oscillating piston. This equation guarantees that the motion remains periodic in spite of the cumulative effects of the nonlinear terms. The properties of shock waves are summarized, and the behavior of the Riemann invariants through the shocks is discussed. The energy balance and the effect of viscosity are evaluated, and resonance at higher frequencies is observed. For an inviscid gas, the amplitude at resonance is found to be finite and determined by nonlinear effects. Final results, including friction, are shown in graphical form.

INTERNAL CHARACTERISTICS AND PERFORMANCE OF AN AERODYNAMICALLY CONTROLLED, VARIABLE-DISCHARGE CONVERGENT NOZZLE. J. G. McArdle. US, NACA TN 4312, July, 1958. 33 pp. Investigation showing that a considerable reduction of the effective flow area can be obtained in a convergent exhaust nozzle by injecting a high-pressure, high-temperature secondary jet into the nozzle near the exit. Analytical expressions, relating the performance with significant design and operating variables, are developed, and necessary experimental factors are evaluated by using a 4-in.-exit-diameter nozzle with unheated pressurized air discharged into the atmosphere. It is shown that some configurations, altered to operate as jet deflectors, produce significant values of side force, but, at the same time, operate at reduced effective flow area.

ABSCHAETZUNG DES REGULARITAETSGEBIETES UND NUMERISCHE DARSTELLUNG TRANSSONISCHER DUESENSTROEMUNGEN. E. Martensen. (GAMM Annual Meeting, Saarbrücken, Apr. 8-12, 1958.) Aero. Versuchsanstalt, Göttingen, Bericht No. 58/A/04, Feb. 13, 1958. 11 pp. In German. Investigation of a compressible, stationary, and inviscid potential flow in plane Laval nozzles. In the transonic case the flow is assumed to have a linearly increasing velocity distribution along the nozzle axis. Includes presentation of experimental results and description of the method of calculation.

Jet Flaps & Wings

THEORY OF TWO-DIMENSIONAL AEROFOIL WITH JET FLAP. Włodzimierz Prosnak. Arch. Mech. Stosowanej, No. 1, 1958, pp. 3-24. 16 refs. Investigation of the influence of a jet flap on the aerodynamic coefficients of an airfoil, assuming perfect fluid and steady plane motion. The flow past a circular profile with jet flap is considered; it can be mapped into another profile by using known methods of conformal mapping. Airfoils which can be obtained by using Joukowski's transformation are studied, and the pitching moment is determined. Simple closed formulas for the aerodynamic coefficients of two-dimensional profiles with jet flaps are derived and the obtained results are analyzed.

SOME CONTRIBUTIONS TO JET-FLAP THEORY AND TO THE THEORY OF SOURCE-FLOW FROM AEROFOILS. L. C. Woods. Gt. Brit.,

ARC CP 388, 1958. 37 pp. 13 refs. BIS, New York, $0.90. Theoretical study of the thrust, lift, and moment on an airfoil due to a two-dimensional jet of air ejected from the trailing edge at an angle τ to the main stream. It is rigorously proved that in subsonic compressible flow the ideal thrust of the jet is independent of the exit angle τ (angle between main stream and jet flow). The theory for the lift and moment is developed for incompressible flow only and is not rigorous, being based on the assumption that jets of equal momentum and at equal values of τ have essentially the same influence on the main stream. The theory is in satisfactory agreement with the experimental values available.

THE LIFT ON A THIN AEROFOIL WITH A JET-AUGMENTED FLAP. D. A. Spence. Aero. Quart., Aug., 1958, pp. 287-299. Application of a method developed previously for calculating the lift on a thin jet-flapped airfoil to the case in which the jet enters the main stream tangentially from a deflected flap. The calculated lift derivatives show that the effectiveness of the jet flap scheme may be increased by blowing over flaps of the order of 20% or 30% of the chord, rather than over the small "shrouds" which have hitherto been proposed.

PRESSURE-PLOTTING MEASUREMENTS ON AN 8 PER CENT THICK AEROFOIL WITH TRAILING-EDGE FLAP BLOWING. J. Williams and A. J. Alexander. Gt. Brit., ARC R&M 3087, 1958. 34 pp. BIS, New York, $2.16. Description of wind-tunnel experiments on an 8% thick airfoil between end plates, with blowing from a slot in the knee of a 25% chord trailing-edge flap, to improve the lifting efficiency of the flap. Both the blowing-slot width and the position are varied. The sectional lift and pitching moment are derived by chordwise integration of the surface static pressures measured at the mid-span station. Tuft observations and surface-pressure measurements are made to determine the extent of the turbulent separation region on the trailing-edge flap and of the laminar separation bubble on the airfoil nose. The blowing momentum required to prevent flow separation on the flap, at a given angle and zero wing incidence, was less conclusive than might have been expected from earlier two-dimensional experiments. The separation bubble began to expand markedly when the incidence reached only a few degrees.

USE OF THE COANDA EFFECT FOR OBTAINING JET DEFLECTION AND LIFT WITH A SINGLE FLAT-PLATE DEFLECTION SURFACE. Appendix A, B - PRESSURE DISTRIBUTION OVER DEFLECTION PLATES. Appendix C - CORRELATION OF PRESSURE DISTRIBUTION IN TERMS OF RATIO OF LOCAL SURFACE DISTANCE TO NOZZLE HEIGHT RAISED TO n-POWER. Appendix D - CENTER-OF-PRESSURE LOCATION ON DEFLECTION PLATE. U. H. von Glahn. US, NACA TN 4272, June, 1958. 49 pp. 10 refs. Presentation of performance characteristics similar to those for a flap immersed in an airstream in quiescent air for the case of nozzle-deflection-plate configurations using the Coanda effect for achieving jet deflection and vertical lift. With a simple flat-plate deflection surface the optimum ratio of lift to undeflected thrust follows a sine function with a plate deflection angle. Because of jet detachment from the deflection plate, the configurations studied were limited to specific deflection angles depending on nozzle height. An empirical relation is derived for predicting the required plate length in terms of nozzle height for achieving optimum performance at a given deflection-plate angle and pressure ratio.

FULL-SCALE WIND-TUNNEL TESTS OF A 35° SWEPTBACK-WING AIRPLANE WITH BLOWING FROM THE SHROUD AHEAD OF THE TRAILING-EDGE FLAPS. W. H. Tolhurst, Jr. US, NACA TN 4283, July, 1958. 40 pp. Investigation to determine the effect of flap location on the jet-flow momentum coefficient required to control the flap boundary layer when blowing from the wing shroud. The data presented show the change in lift coefficient with changes in momentum coefficient for various flap deflections, flap positions, and nozzle heights. The results show that flap locations near the nozzle permitted control of the flap boundary layer with minimum jet-momentum requirements; with increasing distance of the flap from the nozzle, the momentum required for boundary-layer control increased rapidly. The momentum-coefficient requirements for shroud blowing from a plain flap compare favorably with the requirements for blowing from a nozzle located in the upper surface of a plain flap. It is also found that the jet momentum coefficient is not a satisfactory correlating parameter for blowing with large nozzle heights and low duct pressures.

WIND-TUNNEL INVESTIGATION AT LOW SPEEDS OF FLIGHT CHARACTERISTICS OF A SWEPTBACK-WING JET-TRANSPORT AIRPLANE MODEL EQUIPPED WITH AN EXTERNAL-FLOW JET-AUGMENTED SLOTTED FLAP. J. L. Johnson, Jr. US, NACA TN 4255, July, 1958. 32 pp. Presentation of test results from experiments made over a lift-coefficient range up to approximately 12.5 for a range of angles of attack from -12° to about 13°. For lift coefficients higher than 6, a downwardly directed nose jet is used to supplement the trimming power of the horizontal tail. Flight characteristics of the model without the nose jet were generally satisfactory up to a lift coefficient of about 4. Flight characteristics of the model with the nose jet are generally satisfactory over the test lift-coefficient range, but the control effectiveness provided by conventional control surfaces is barely sufficient to maintain flight at a lift coefficient of 12.5.

Performance

LE COUPLAGE PAR INERTIE ET SES REPERCUSSIONS SUR LES QUALITES DE VOL. J. Czinzenheim, P. Jaillard, and M. Pottier. Docaéro, May, 1958, pp. 15-28. In French. Determination of the velocity distribution over turbine blades including: historical survey and general data on the problem of inertia coupling, derivation of general and simplified equations, evaluation of aerodynamic forces and aerodynamic derivatives, and gyro-

scopic effects of the power unit. Also presented are some special problems - the case of cross coupling, study of tail unit loads, the Phillips criteria, and the phenomena of uncontrolled roll. Various parameters studied cover flight, maneuver, and aerodynamic parameters. The case of artificial stabilization is also analyzed and the limitations of the angular velocity and control surface deflections are defined.

Stability & Control

LOW-SPEED EXPERIMENTAL DETERMINATION OF THE EFFECTS OF LEADING-EDGE RADIUS AND PROFILE THICKNESS ON STATIC AND OSCILLATORY LATERAL STABILITY DERIVATIVES FOR A DELTA WING WITH 60° OF LEADING-EDGE SWEEP. H. S. Fletcher. US, NACA TN 4341, July, 1958. 45 pp. 15 refs. Description of tests on six delta-wing models in the Langley stability tunnel. The wings were oscillated in yaw about their vertical axes. Results indicate noticeable decreases in all the derivatives due to an increase in leading-edge radius at angles of attack above approximately 12°. Profile thickness effects are found to be small for the yawing-moment derivatives; however, the data show that an increase in profile thickness causes appreciable increases in the combination oscillatory derivatives of rolling moment with respect to yawing velocity and rolling moment with respect to sideslip acceleration, as well as large decreases in the effective-dihedral parameter at angles of attack above 8°. The static derivatives of rolling and yawing moment with respect to sideslip C_{ℓ_β} and C_{n_β} show essentially the same effects of leading-edge radius and profile thickness as the oscillatory derivatives.

WIND-TUNNEL INVESTIGATION OF THE HIGH-SUBSONIC STATIC LONGITUDINAL STABILITY CHARACTERISTICS OF SEVERAL WING-BODY CONFIGURATIONS DESIGNED FOR HIGH LIFT-DRAG RATIOS AT A MACH NUMBER OF 1.4. P. G. Fournier. US, NACA TN 4340, July, 1958. 42 pp. Test results indicate that the use of wing twist provided essentially no improvement in maximum lift-drag ratios over that of the basic flat wing; however, use of a wing having both camber and twist raised the value of the maximum lift-drag ratio. In general, fixing transition reduced the value of maximum lift-drag ratio by about 1.5 for the test conditions, but had little effect on longitudinal stability. Body indentation has essentially no effect on either longitudinal stability characteristics or maximum lift-drag ratios within the Mach Number range investigated.

Wings & Airfoils

DEUX METHODES DE CALCUL RHEOELECTRIQUE APPLIQUEES AUX SURFACES PORTANTES. M. Enselme. La Recherche Aéronautique, May-June, 1958, pp. 35-42. In French. Development of two methods of rheoelectric calculation applied to lifting surfaces. Previous investigations, based on the perturbation-velocity or acceleration potentials, performed by Malavard and Duquenne on the use of an electric tank are discussed. Analysis covers means for overcoming the limitations of the previously used method by suitable design of conducting and insulating areas in the analog. Application and results for a constant-chord wing of 45° sweepback and aspect ratio 4 are described in detail.

SPECIAL BODIES ADDED ON A WING TO REDUCE SHOCK-INDUCED BOUNDARY-LAYER SEPARATION AT HIGH SUBSONIC SPEEDS. R. T. Whitcomb. US, NACA TN 4293, June, 1958. 48 pp. Investigation carried out on a relatively thick 35° sweptback wing of aspect ratio 7.05 mounted on a contoured fuselage. Studies of the boundary-layer flow indicate that addition of the bodies resulted in a significant lessening of the separation on this configuration at high subsonic Mach Numbers. Marked reductions in drag were associated with the improved flow. For a lift coefficient of 0.3, the added bodies reduced the drag coefficient by approximately 0.01 at a Mach Number of 0.92 and increased the drag-rise Mach Number by about 0.05. The additions also greatly reduced pitch-up at the lift coefficients and Mach Numbers of the test. With an increase in sweep of the wing to 40°, the effectiveness of the added bodies in improving the drag and pitching-moment characteristics was increased.

SOME ASPECTS OF DRAG REDUCTION FOR LIFTING WING-BODY COMBINATIONS AT SUPERSONIC SPEED. Lu Ting. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 445 (AFOSR TN 58-423) [AD 158226], May, 1958. 27 pp. Investigation showing that for a prismatic body of rectangular cross section with given volume (or cross section area), mounted on a mid-wing of given span and swept back, the lift drag ratio of the wing-body combination with favorable antisymmetric modifications will be higher if the basic body has a lower height-width ratio. An estimation of the gain or loss in the lift-drag ratio in the selection of one cross section's shape against another is given. The reduction of drag due to favorable contouring causes little change in the friction drag. It is shown that for the wing-body configurations studied, the effect of contouring the vertical surface which does not support lift will result in an increase of 5 to 10% in the lift-drag ratio. Calculations for a simple model of wing-body combination are made to study the effect of favorable interference at off-design conditions. The results show that for a given value of $C_L\sqrt{M^2-1}$ the drag increases gradually as M deviates from the design value.

A THEORETICAL AND EXPERIMENTAL INVESTIGATION OF THE FLOW OVER A FAMILY OF RECTANGULAR WINGS OF BICONVEX SECTION AT M = 1.42. R. C. Lock. Gt. Brit., ARC R&M 3055, 1958. 43 pp. 23 refs. BIS, New York, $2.70. Presentation of measurements of the pressure on the upper surface of the wing, and of pressure and flow direction in the neighborhood of the wing tip. Direct shadow photography and observation of surface oil patterns enabled various details of the flow to be visualized. The results are correlated with the linearized theory and with certain

second-order modifications of this theory. It is found that, in general, the linearized theory provides a sufficient approximation to the detailed flow only for the thinnest wing at very small incidences. In most cases the suggested modifications effect a considerable improvement.

IDEALIZED WINGS AND WING-BODIES AT A MACH NUMBER OF 3. E. D. Katzen. US, NACA TN 4361, July, 1958. 11 pp. Results of some calculations indicating the possibility of obtaining high lift-drag ratios at a Mach Number of 3 and description of experiments designed to exploit the theory. The relatively high lift-drag ratios calculated are partly realized. A trimmed lift-drag ratio of 9 is obtained instead of the estimated value of 11 at the maximum test Reynolds Number of 3.5 million.

A FUSELAGE ADDITION TO INCREASE DRAG-RISE MACH NUMBER OF SUBSONIC AIRPLANES AT LIFTING CONDITIONS. R. T. Whitcomb. US, NACA TN 4290, June, 1958. 38 pp. Investigation concerning the addition of fuselage volume on top of the forward portion of a fuselage for the purpose of increasing the drag-rise Mach Number of subsonic airplanes at lifting conditions. The additions are designed on the basis of the area rule and other important considerations to provide greater practicability of application compared with shapings previously investigated. The addition increased the drag-rise Mach Number by an increment of approximately 0.03 for a configuration having a wing with moderate thickness and 35° sweepback at a lift coefficient of 0.3. The additions increased the nonlinearities of the variations of pitching moment with lift.

AEROELASTICITY

DEFINITIONS OF DAMPING IN AIRCRAFT RESPONSE. T. Czaykowski. Aircraft Eng., Aug., 1958, pp. 227-232. Review of the usual definitions of damping in oscillatory modes and presentation of a new definition. Formulas, numerical tables, and graphs permit a rapid comparison between the different definitions. Response formulas for three fundamental types of disturbances are presented. These can be used for the derivation of various expressions characterizing dynamic properties of any mode which is equivalent to a damped system of one degree of freedom.

UNTERSUCHUNGEN ZUR STABILITÄT NICHTLINEARER ERZWUNGENER SCHWINGUNGEN VON EINEM FREIHEITSGRAD. G. Helke. DVL Bericht No. 55, May, 1958. 20 pp. Westdeutscher Verlag, Köln & Opladen. In German. Investigation of the stability of forced vibrations in nonlinear systems with one degree of freedom, using methods derived by Poincaré and Liapunov.

UTILIZATION OF EXPERIMENTAL RESULTS IN FLUTTER ANALYSIS. Erik Mollð-Christensen. J. Aero/Space Sci., Oct., 1958, pp. 635-643. 14 refs. Discussion of the problem of obtaining and utilizing experimental data in flutter analysis. The equations of motion of a flexible wing in an air stream are given. Two methods of approximation of the deflection amplitude distribution are considered: approximation by natural modes, and approximation by discrete ordinates. A rough method of estimating changes in flutter speed due to parameter changes is outlined. Equations for a set of tests and their use are described. The precision of information obtained from tests is considered and the resulting accuracy of the flutter prediction discussed.

SUPERSONIC WIND-TUNNEL FLUTTER TESTS OF TWO RECTANGULAR WINGS. P. R. Guyett. Gt. Brit., ARC R&M 3080, 1958. 15 pp. BIS, New York, $0.99. Description of flutter tests made on two rectangular wings of aspect ratio 4 in a supersonic wind tunnel at Mach Numbers 1.6 and 2.0 using a technique in which a structural stiffness was varied to produce flutter at the Mach Number. Comparative calculations were made for each test configuration using arbitrary modes based on the resonance characteristics of the wings. The calculated and experimental critical stiffnesses and frequencies are in reasonable agreement, though, in general, the former are rather higher than the test values. It is shown theoretically that structural damping has an important effect on the calculated stiffnesses and frequencies for the test wings, and that structural damping in pitch can be destabilizing.

WIND-TUNNEL TESTS ON THE EFFECT OF BODY FREEDOMS ON THE FLUTTER OF A MODEL WING CARRYING A LOCALISED MASS. D. R. Gaukroger and E. W. Chapple. Gt. Brit., ARC R&M 3081, 1958. 33 pp. BIS, New York, $2.07. Presentation of test results for the flutter of a sweptback wing carrying a localized mass and having symmetric and antisymmetric freedoms of the root. The tests were made on a model wing of 23° sweepback, the chordwise and the spanwise positions of a localized mass being varied for two localized mass values. The inertia conditions of the fuselage were constant and representative of full scale in most of the symmetric flutter tests. The fuselage rolling moment of inertia was varied for the antisymmetric tests. Results indicate that, in general, the symmetric flutter case is more critical than the antisymmetric for masses at outboard positions on the wing, but for heavy inboard masses the antisymmetric case may be more critical. Graphical representations of symmetric and antisymmetric flutter are given. It appears that the results are too complex for predicting the effects of mass loading on the flutter of particular aircraft.

AVIATION MEDICINE, SPACE MEDICINE

UNTERSUCHUNGEN ÜBER DAS AUFTRETEN INTRAVASALER GASBLASEN NACH RASCHER DRUCKERNIEDRIGUNG IN ABHÄNGIGKEIT VON VASOTONUS. E. Schmitz. DVL Bericht No. 69, June, 1958. 23 pp. 15 refs. Westdeutscher Verlag, Köln & Opladen. In German. Description of tests on albino rats performed as part of an investigation on the occurrence of intravascular embolism after rapid decompression. Results of ex-

periments are presented and methods used for the reduction of gas content are evaluated.

INSTRUMENTS

Flow Measuring Devices

EXTENDED APPLICATIONS OF HOT-WIRE ANEMOMETRY TO HIGH-SPEED TURBULENT BOUNDARY LAYERS. M. V. Morkovin and R. E. Phinney. Johns Hopkins U., Dept. Aero. Rep. (AFOSR TN 58-469) [AD 158279], June, 1958. 142 pp. 50 refs. Application to the case of wires in yaw of the method of local linearization for the response of a general nonlinear hot-wire anemometer system when the wire is immersed in a fluctuating compressible gas. An X-probe was designed and used for boundary-layer measurements from which Reynolds stress and the energy flux can be obtained. The satisfactory agreement between results of measurements with sleeved and bare wires, made both of tungsten and platinum-10% rhodium with a variety of holders, provided further verification of the rather complicated methods of measurement and interpretation.

DEBIMETRE A COURT TEMPS DE REPONSE. A. Moutet. La Recherche Aéronautique, May-June, 1958, pp. 13-25. In French. Description of experiments on a rotary type flow meter with the rate of rotation proportional to the flow. The rotating blades are equiped with platinum-wire inserts at the tips, acting as mirrors for an electro-optical measuring system (rotational speed), or incorporate ferroxcube inserts for an electromagnetic measuring system. Includes description of various types of flow meters, as well as the method for free-flight model application.

MATERIALS

Metals & Alloys

EFFECT OF TEMPERATURE ON DYNAMIC MODULUS OF ELASTICITY OF SOME STRUCTURAL ALLOYS. L. F. Vosteen. US, NACA TN 4348, Aug., 1958. 19 pp. 15 refs. Determination of the effect of temperature on Young's modulus of elasticity for 2024-T3 and 7075-T6 aluminum alloys, AZ31A-0 magnesium alloy, RS-120 titanium alloy, and type 303 stainless steel by flexural vibration tests of beam specimens at temperatures from room temperature to 900°F. The data show that the dynamic modulus decreases with temperature but does not increase as rapidly as the static modulus. It is shown that the difference between static modulus and dynamic modulus is due to internal friction and cannot be attributed to creep.

AN EVALUATION OF STRUCTURAL SHEET MATERIALS IN MISSILE APPLICATIONS. Appendix - MECHANICAL PROPERTIES OF SHEET MATERIALS USED IN ANALYSIS. George Gerard. Jet Propulsion, Aug., 1958, pp. 511-520. 19 refs. Comparison of material efficiencies of various alloy classes utilizing an envelope representing the highest mechanical properties of all commercial materials of a given alloy class in the temperature range between room temperature and 1,200°F. The tension efficiencies are presented in terms of yield and ultimate short-time tensile strength. A minimum weight analysis is made for both stiffened and unstiffened circular cylinders under compression. The comparative efficiencies of the various materials are then considered in terms of compressive yield and crippling strength, as well as for unstiffened and stiffened cylinders.

MISSILES

ON FLIGHT TRAJECTORIES IN THE NEIGHBORHOOD OF A KNOWN TRAJECTORY. R. M. Rosenberg. Franklin Inst. J., Aug., 1958, pp. 109-128. Discussion of the nominal (unperturbed) trajectory for pilotless aircraft and computation of trajectories for conditions neighboring on the nominal ones. The integration of the equations of motion of the aircraft yields the correct flight trajectory only if all parameters of the problem, all functional relations implicit in the coefficients of the equations, and all initial conditions are known with precision. Formulas for computing trajectories neighboring on nominal ones are derived regardless of the cause of perturbations. The perturbation equations are discussed and dealt with by considering the time-dependent coefficients as constant during sufficiently short time intervals. The resulting equations yield the perturbed flight path under any disturbances which lie within the scope of the theory.

PHYSICS

THE CONTAINMENT OF PLASMA BY THE PINCH DISCHARGE. George Thomson. Philos. Mag., 8th Ser., Aug., 1958, pp. 886-896. Calculation of the effects relevant to the loss of heat by conduction from a thermonuclear device of the zeta type. The problem studied is that of a strong current flowing axially in a plasma with cylindrical geometry, in which the charged particles of the plasma will be prevented from striking the cylindrical wall both by the self-magnetic field of the current and, in the case of positive ions, by the electric field due to the negative charge in the region of the current. It is shown that in order to reduce the loss of heat by conduction to a value less than the energy generated in the discharge by a thermonuclear reaction in deuterium, it is necessary either to have a magnetic field corresponding to a current of the order of a thousand million amps, or to have a substantial electric field, giving a radial potential difference between the axis and wall of the order of 250-500 kv, together with currents of a few million amps.

HIGH-ALTITUDE ATMOSPHERIC DENSITY. T. E. Sterne. Phys. Fluids, May-June, 1958, pp. 165-170. 17 refs. Discussion of atmospheric density values obtained from the motion of artificial satellites at altitudes between 186 and 656 kilometers. Densities inferred from satellites are higher than for the ARDC model of the atmosphere. These densities are about ten times higher than those inferred from rocket-borne ionization gages between 186 and 230 kilometers. The inference of atmos-

pheric density from rocket-borne ionization gages is discussed critically, and densities obtained are considered to be inferior in reliability to the satellite densities. The latter suggest molecular scale temperatures higher than those of the ARDC model in one or more regions of altitude above 80 kilometers.

POWER PLANTS

Jet & Turbine

THEORETISCHE BERECHNUNG DES BY-PASS-TRIEBWERKES. I - UNTERSCHALL-BEREICH. O. Lutz and W. Dietze. DFL Inst. Strahltriebwerke Bericht No. 64, Oct., 1956. 54 pp. 11 refs. In German. Theoretical calculation of the by-pass engine and evaluation of its efficiency as compared to the pure jet. The parameters influencing the fuel consumption and specific thrust are investigated and the results are presented in graphical form. It is shown that the optimum by-pass value lies between 0.35 and 0.75, which can be increased with higher combustion chamber temperature, and that altitude has little effect on these values.

Ram-Jet & Pulse-Jet

ANALYSE SIMPLIFIEE DU FONCTIONNEMENT DES STATOREACTEURS MODERNES. C. Bourgarel. Docaéro, May, 1958, pp. 55-66. In French. Survey of available data and presentation of a simplified analysis of the operation of modern ramjets. The description includes design and operational parameters: compression stage - different operating regimes, output and total pressure of supersonic air inlets, shape and location of shock waves, interaction between the boundary layer and the downstream wave, subsonic diffuser; combustion stage - characteristic values, dimensioning, and problems of combustion chamber design; expansion stage - nozzle shape, the effect of heating, Mach Number, altitude, and deformation parameters, as well as thermal, operational, and structural limitations.

STABILIZZAZIONE DELLA FIAMMA NEI COMBUSTORI DEGLI AUTOREATTORI. Gaetano Salvatore. L'Aerotecnica, Apr., 1958, pp. 111-116. 11 refs. In Italian. Theoretical investigation of flame stabilization in ram-jet combustors by means of bluff bodies, and presentation of a method for determining the possible field of stability. The variation of the stability curves with various parameters is described, the flame stabilization is analyzed for low and high Reynolds Numbers, and the causes of this behavior pattern are evaluated.

RESEARCH, RESEARCH FACILITIES

Wind Tunnels

SHOCK-FRONT-THICKNESS MEASUREMENTS BY AN ELECTRON BEAM TECHNIQUE. H. N. Ballard and Douglas Venable. Phys. Fluids, May-June, 1958, pp. 225-229. 16 refs. Description of an electron beam densitometer for investigating the structure of a shock front in low-density gases. The parameters measured by this technique are directly related to those used in the accepted definition of shock front thickness. An approximate method of data reduction is used for treating preliminary results. It is shown that the measured value of the thickness of a Mach 4 shock in argon is about three mean free paths, measured in terms of the undisturbed gas. The technique and existing apparatus would be very useful in examining relaxation phenomena behind shock waves.

ROTATING WING AIRCRAFT, HELICOPTERS

MATRIX METHOD FOR OBTAINING SPANWISE MOMENTS AND DEFLECTIONS OF TORSIONALLY RIGID ROTOR BLADES WITH ARBITRARY LOADINGS. Appendix - BASIC INTEGRATING MATRICES. A. P. Mayo. US, NACA TN 4304, Aug., 1958. 50 pp. Presentation of a method which permits solutions for cantilever, semirigid (teetering), and fully articulated (hinged) blades in both hovering and steady forward flight. The effect of blade structural damping, omitted in other methods, is included in the present method which is comparatively short and does not require the mode shapes or natural frequencies to be known.

HIGHER HARMONIC ROTOR CONTROL. P. R. Payne. Aircraft Eng., Aug., 1958, pp. 222-226. Study on the elimination of the retreating blade stall speed limitation for helicopters by means of an appropriately programed feathering input for the general case of a rigid flapping blade with hinge constraint. It is concluded that second harmonic feathering alone will not be particularly effective in delaying the stall limit, but that a suitable program of several higher harmonic inputs will enable the retreating blade stall limit to be pushed beyond the advancing blade compressibility limit.

THE INFLUENCE OF THE WAKE ON THE FLUTTER AND VIBRATION OF ROTOR BLADES. J. P. Jones. Aero. Quart., Aug., 1958, pp. 258-286. Derivation of a theory which takes into account the influence of the wake on the aerodynamic derivatives of an oscillating rotor blade. It is shown that the most important parameter is the number of cycles of the oscillation which occur during one revolution of the rotor. For integral values of this parameter the flexural damping is shown to become very small at small angles of incidence. The flutter characteristics of a simple rotor blade are calculated on the basis of this theory, and it is found that the wake causes radical changes in the critical speeds.

WIND-TUNNEL INVESTIGATION OF EFFECTS OF SPOILER LOCATION, SPOILER SIZE, AND FUSELAGE NOSE SHAPE ON DIRECTIONAL CHARACTERISTICS OF A MODEL OF A TANDEM-ROTOR HELICOPTER FUSELAGE. J. L. Williams. US, NACA TN 4305, July, 1958. 44 pp. Presentation of test results showing the model to be directionally unstable at certain positive angles of attack. This instability is found to result, in general, from a large unstable fuselage moment caused by the potential flow pressure peaks in the vi-

cinity of the fuselage nose and a low tail effectiveness, a factor shown to be associated with the adverse effect of the fuselage sidewash on the tail. Substitution of a blunt nose section for the tapered nose section resulted in a fuselage-tail configuration which is directionally stable at all angles of attack except that of 30°.

SPACE TRAVEL

DEPARTURE AND RETURN IN INTERPLANETARY FLIGHT. K. J. Bossart. (IAS Natl. Midwest. Meeting, St. Louis, May 12-14, 1958.) Aero/Space Engrg., Oct., 1958, pp. 44-52. Formulation of basic rules to achieve optimization of interplanetary flight. Calculations are performed for hyperbolic orbits of capture or escape, as well as for closed orbits of convenience, either elliptic or circular. Transfer from elliptic closed orbits to a hyperbola is calculated for five different cases. Departure from a precessed circular orbit and a precessed elliptic orbit is found for the five cases. Methods of return to earth are discussed, and the best method appears to be that of a ferry vehicle traveling to the space-vehicle capture orbit and then returning to the earth.

ASPETTI FONDAMENTALI DEI PROBLEMI RELATIVI ALLA CREAZIONE DI SATELLITI ARTIFICIALI ED ALLA NAVIGAZIONE COSMICA. Gelsomino Metallo. Riv. Aero., June, 1958, pp. 873-900. In Italian. Discussion covering the basic aspects of the problem of artificial satellites in relation to other celestial bodies, and celestial navigation. Included are such topics as trajectories, velocities, gravity, propulsion systems, and space stations. Available data on the Soviet as well as American satellites are analyzed, and future possibilities are evaluated.

LES DEUX PREMIERS SPOUTNIKS. D. Laurent. Docaéro, May, 1958, pp. 29-48. 16 refs. In French. Discussion covering the first two Soviet satellites, with a general survey of available satellite data on the motion, the information obtained and its application, and the choice of the orbital plane and altitude. The specific data on Sputnik I and II include design and operating characteristics, the problem of the experimental dog, and the launching device.

STRUCTURES

LOSS OF TORSION STIFFNESS UNDER LOAD. Ll. E. Hackman. Aero/Space Engrg., Oct., 1958, pp. 53-57, 64. Development of an analytical method for predicting the loss of GJ. The loss of G is derived by first finding the shear and the critical shear stress and then combining them in a ratio in order to determine the percentage loss. The torsional stiffness of a section in which a loss of G occurred is calculated by standard closed section methods. Application is made to the calculation of rib bending losses. A comparison of test results with analytical predictions shows satisfactory agreement within the accuracy of the tests performed.

CONCENTRATED FORCE IN THE INTERIOR OF A TRANSVERSELY ISOTROPIC ELASTIC SEMI-INFINITE SPACE. Zofia Mossakowska. Arch. Mech. Stosowanej, No. 2, 1958, pp. 233-251. 12 refs. Analysis to determine the stress field for an isotropic semispace loaded by a concentrated force in any direction and attached to any point inside the semispace. The plane bounding the semispace is parallel to the plane of symmetry. Solutions are obtained separately for each of the three components of force in three different cases of boundary conditions.

METHOD OF SPLIT RIGIDITIES AND ITS APPLICATION TO VARIOUS BUCKLING PROBLEMS. P. P. Bijlaard. US, NACA TN 4085, July, 1958. 97 pp. 51 refs. Presentation of a comprehensive treatise on the method of split rigidities. The applications are divided into problems where all component modes, into which the actual behavior of a composite structure is split, have the same boundary conditions and into those where these boundary consitions differ. Examples of the first type include sandwich columns with various boundary conditions, columns with batten plates, and latticed columns; examples of elastic and plastic buckling of sandwich plates with orthotropic core and of corrugated-core sandwich plates are also given. An explicit formula is derived for the buckling stress of stringer panels which is an example of the second type of problem.

Beams & Columns

BENDING AND VIBRATION OF ELASTICALLY RESTRAINED BEAMS. C. L. Kantham. Aero. Soc. India J., Feb.-Mar., 1958, pp. 1-5. 12 refs. Presentation of the values of deflection and vibration for various values of elastic restraint and position of load in the case of beams with a concentrated load, having end conditions varying from clamped to simply supported edges.

Elasticity & Plasticity

ON THE VARIATION OF POISSON'S RATIO IN THE SOLUTION OF ELASTIC PROBLEMS. R. J. Knops. Quart. J. Mech. & Appl. Math., Aug., 1958, pp. 326-350. 10 refs. Development of equations enabling the general solution to be deduced from the known one by assuming that the solution to a three-dimensional elastic boundary-value problem for a particular Poisson's ratio is known. The known solution need not necessarily correspond to a real Poisson's ratio; an infinite value, for example, reduces the problem to one in potential theory. Three problems are discussed to illustrate the method, one deals with a semi-infinite body with plane rigidly constranied boundary, and two with a solid bounded by two right circular coaxial cones loaded by a force acting at the common vertex in the directions along, and perpendicular to, the common axis.

PLASTIC FLOW IN THE EXTRUSION OF RIBS ON FLAT PLATES. Wang Jen. Scientia Sinica, May, 1958, pp. 505-515. 19 refs. Analysis of the

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extrusion of parallel ribs on a thin flat plate as a problem in the theory of plane strain for perfectly plastic rigid materials. It is assumed that the friction between the flat plate and the lower die surface is sufficiently large so that there is no slip between them. The coefficient of friction μ between the flat plate and the upper die is taken to be zero or larger than 0.175, corresponding to free slip and no slip between these surfaces, respectively. Slip line fields and their corresponding hodographs and stress trajectories are found for different ratios of k/a (k being the thickness of the plate, and $2a$ the width of the rib). The pressure distributions and the average pressure for different reduction ratios on the upper die are given. The results are compared to those of inverse extrusion. A comparison between the exact solution derived and Iliushin's results is also made. The deformation of an originally square grid is used to show the strain distribution.

A PLANE STRESS PROBLEM IN PIECEWISE LINEAR PLASTICITY. W. E. Boyce. Rensselaer Polytech. Inst. Dept. Math. RPI MathRep. 16 (AFOSR TN 58-629) [AD 162159], Aug. 1, 1958. 24 pp. Analysis from a three-dimensional point of view of a plane stress problem, the bending of a rigid-plastic simply supported circular plate by a uniform load, using Praeger's hardening law. This more elaborate theory predicts displacements less than half as large as those obtained for the same loads using the two-dimensional theory. The dependence of the post-yield stresses and displacements on the magnitude of the initial yield stress is also examined.

VARIATIONAL THEORY FOR FRICTIONAL SLIP IN THE CONTACT PLANE IN PLASTIC COMPRESSION. Liu Shu-i. Scientia Sinica, Apr., 1958, pp. 413-423. Analysis treating the problem of plane friction in a variational manner with the condition of minimum frictional work as the general law governing the slip direction instead of the condition of least resistance or that of shortest distance. The variational law yields two different laws for two different types of friction lines. In both cases the variational law yields the invariant solution for the frictional stress distribution as an exponential form containing an unknown scale function to be determined by plasticity analysis; one solution has been worked out. In the special case of radial extrusion, the frictional stress distribution can be completely specified by the variational law alone without plasticity analysis.

SOME IDENTITIES ON STRUCTURAL FLEXIBILITY AFTER BUCKLING. E. H. Mansfield. Aero. Quart., Aug., 1958, pp. 300-304. Derivation of certain identities in which the post-buckling flexibility of a structure having a post-buckling mode that varies with the load is related to the post-buckling flexibility of a structure constrained to deflect in a constant post-buckling mode. The identities have a useful application in determining the flexibility and the rate of change of flexibility with load at the onset of buckling.

Plates

MIXED BOUNDARY VALUE PROBLEMS FOR RECTILINEAR PLATES. II. G. A. Nariboli. Arch. Mech. Stosowanej, No. 2, 1958, pp. 129-142. 12 refs. Derivation of solutions by means of a vortex analogy for two types of eigenvalue problems with mixed boundary conditions. It is shown that the potential giving the least buckling load is higher than that giving the first mode of vibration. For right-angled triangles having a clamped side of the same length, the proportionate rise due to clamping increases with a decrease in the angle between the hypotenuse and the clamped side. For isosceles triangles on the same base, the proportionate rise increases with the decrease in angle. By conformal mapping on a circle, the procedure can also be applied to general rectilinear plates.

A CLOSED SOLUTION IN THE CASE OF A SEMI-INFINITE PLATE WITH DISCONTINUOUS BOUNDARY CONDITIONS. II. Artur Kacner. Arch. Mech. Stosowanej, No. 1, 1958, pp. 57-80. Development of a method based on the reduction of the linear differential equation of plate bending to an infinite system of linear equations from which the Fourier coefficients of the function expressing the boundary conditions is determined. A special method for determining the functional form of a certain class of trigonometric series and numerical sums of infinite cylinders is also presented.

Plates with Holes

VARIABLY REINFORCED CIRCULAR HOLES IN STRESSED PLATES. Raymond Hicks. Aero. Quart., Feb., 1958, pp. 213-231. 11 refs. Derivation of an expression for the radial, tangential, and shear stresses in an infinite plate containing a variably reinforced circular hole. The variation in the cross-sectional area of the reinforcement is chosen so that the maximum tensile resistance of the reinforcement occurs at points around the hole where the stresses in the plate tend to be high. It is shown that, when the reinforcement has a given weight, the effect of varying its cross section is to reduce the stress concentration in the plate. The following particular applied stress systems are considered: (a) uniform tension or compression in one direction, (b) uniform shear, (c) unequal principal stresses.

Testing Methods

SPANNUNGSOPTISCHE UNTERSUCHUNGEN VON ROTIERENDEN SCHEIBEN MIT EXZENTRISCHEN BOHRUNGEN. K. Leist and J. Weber. DVL Bericht No. 57, Apr., 1958. 60 pp. 13 refs. Westdeutscher Verlag, Köln & Opladen. In German. Development of a test method for the photoelastic investigation of stresses in rotating turbine discs with excentric holes. The experimental techniques used to obtain the stress pattern are described in detail, as well as the tests on discs of equal thickness with two excentric holes to examine the effect of hole dimension on stress aug-

mentation. Includes description of results and comparison to previous investigations.

Thermal Stress

AEROTHERMOELASTICITY. Milton Rogers. Aero/Space Engrg., Oct., 1958, pp. 34-43,64. 12 refs. Presentation and evaluation of some effects of aerodynamic heating on aeroelastic phenomena, and discussion of the possible impact of this consideration on contemplated design practices. The problems associated with boost-glide vehicles include reduction in torsional stiffness, low aspect ratio aerothermoelastic problem, curling of the leading edge, panel flutter, ablation, control surface effectiveness and rigidity, and fuselage deformations. Application of model testing to the development of optimum theories is discussed. It is shown that complete simulation of all the elastic, inertial, and unsteady aerodynamics, as well as the heat-transfer properties of a prototype is virtually impossible and, therefore, "restricted purpose" models must be employed.

THERMAL STRESS IN CURVED BEAMS. B. A. Boley and E. S. Barrekette. J. Aero/Space Sci., Oct., 1958, pp. 627-643. Analysis of thermoelastic stresses in curved beams of constant properties and constant cross section under temperatures varying in the radial direction only. Good agreement is found between stresses as calculated from elasticity theory and from strength-of-materials theory which assumes that plane sections remain plane. A comparison with the corresponding straight beam formula is also included.

THERMAL STRESSES IN A LONG CYLINDER HEATED IN A DISCONTINUOUS MANNER OVER THE LATERAL SURFACE. Józef Ignaczak. Arch. Mech. Stosowanej, No. 1, 1958, pp. 25-34. Derivation of solutions for thermal stresses in which the method for integrating the equations of thermoelasticity is used by introducing the thermoelastic potential of displacement. It is concluded that the stresses in planes normal to the cylinder axis are due to the normal load. An integral representation of the Heisenberg delta function is obtained by using the Fourier integral theorem. The solution of the problem of heat conduction and thermoelasticity is given in the form of a single Fourier integral. The stresses at infinity are determined by the behavior at infinity of the temperature function.

THERMODYNAMICS

Heat Transfer

HEAT TRANSFER BY LAMINAR FREE CONVECTION IN ENCLOSED PLANE GAS LAYERS. G. Poots. Quart. J. Mech. & Appl. Math., Aug., 1958, pp. 257-273. Presentation of a numerical method for solving the two simultaneous partial differential equations which govern the heat transmission in a closed rectangular cell having hot and cold walls inclined at an angle ϕ to the vertical. The heat transfer through the enclosed gas layer depends on the Rayleigh Number A, the Prandtl Number σ, the aspect ratio of the rectangular cell α, the angle of inclination ϕ of the hot and cold walls to the vertical, and the temperature distribution in the border strips. Preliminary thermal results are given for air enclosed in a cavity having square cross section. A comparison of the theoretical prediction of the heat transfer across the cell with the experimental data of Mull and Reiher can only be made in the region $A = 10^4$. Calculated results and empirical formulas obtained by Jakob agree favorably in this region. Streamlines and isothermals are plotted for $A = 10^4$ and clearly indicate the existence of an isothermal core in the cavity having constant vorticity.

VTOL & STOL

DESIGN CONSIDERATIONS FOR BLC STOL AIRPLANES. F. C. Wagner. Aero/Space Engrg., Oct., 1958, pp. 58-64. 24 refs. Development of a design philosophy for high-lift BLC airplanes and discussion of some developmental problems. The effect of suction- and combined suction-blowing airfoils is described. Design concepts and procedures, as well as correlation of available data, are discussed. The flexible concept of a multiple cell system is suggested; its use leads to practical STOL BLC airplanes. A comparison of BLC systems is made in graphical form.

WATER-BASED AIRCRAFT

ANALYSIS OF ACCELERATION AND WATER PRESSURE DATA OBTAINED ON A P5M-2 IN MODERATELY ROUGH WATER. I, II - ACCELERATION AND PRESSURE DATA. D. A. King and B. E. Phelps. Martin Rep. ER 9918, vol. I, II, Mar., 1958. 102; 392 pp. NavBuAer-sponsored presentation of flight test results for a series of 57 landings and 54 takeoffs made over a wide range of gross weights in waves and swell averaging three-feet high. Data show that maximum accelerations during landing were greater than those during takeoff. The average of the maximum landing accelerations was less than half of the design values for the hull. Similar relationships were observed for water pressures, except that the averages of the maximum pressures near the keel were about 70% of the design pressures. Near the chine the proportion is about 90%.

HYDRODYNAMIC IMPACT LOADS OF A -20° DEAD-RISE INVERTED-V MODEL AND COMPARISONS WITH LOADS OF A FLAT-BOTTOM MODEL. P. M. Edge, Jr. US, NACA TN 4339, Aug., 1958. 36 pp. Investigation to determine the effect of a negative dead-rise angle on the hydrodynamic impact loads over a range of landing conditions. Data are presented in tables and figures as variations of loads and motions (in coefficient form) with time, trim angle, and flight-path angle. In general, the maximum impact loads experienced by the inverted-V model are greater than the loads which have been obtained for a flat-bottomed model; however, for severe impact conditions approaching 0° trim (flat impacts) a trend toward smaller loads than those experienced on a flat bottom is indicated.

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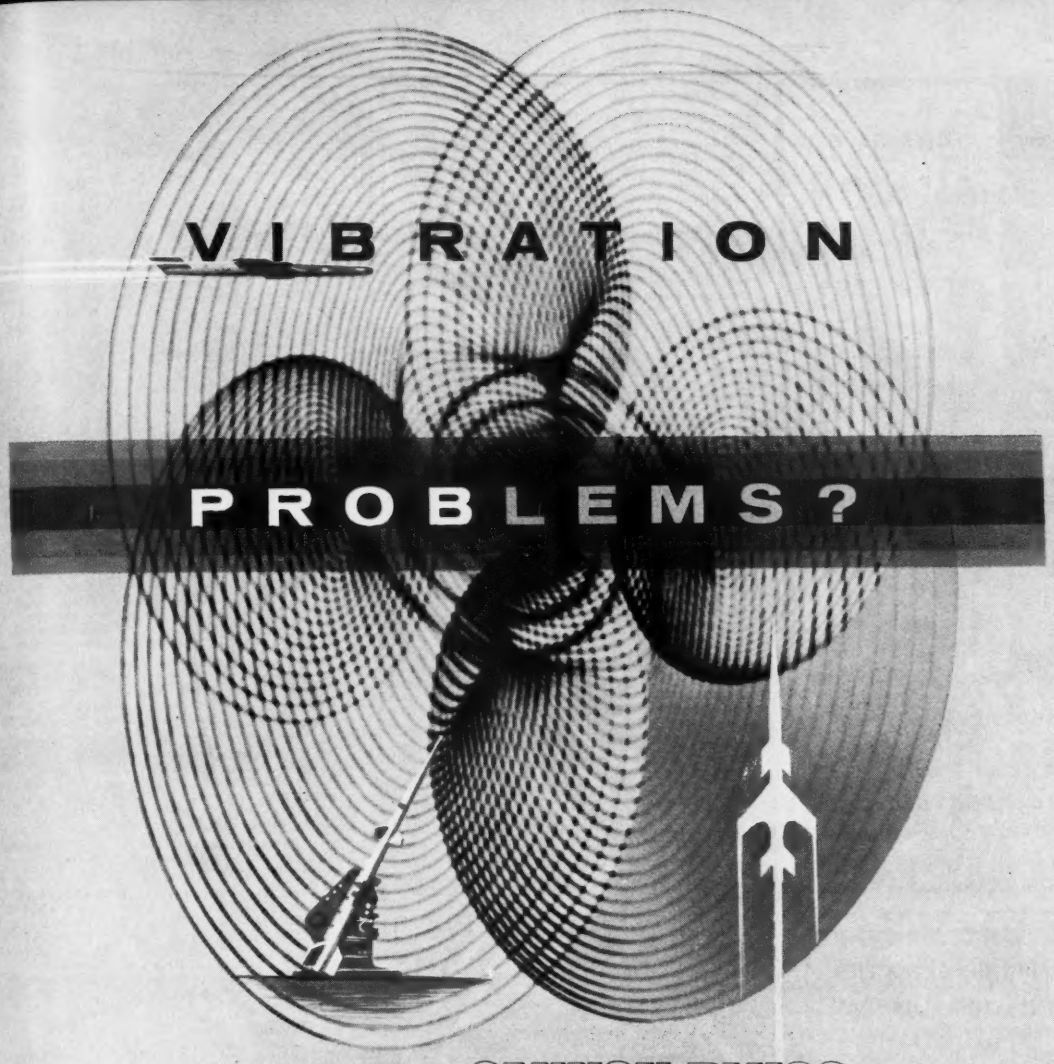

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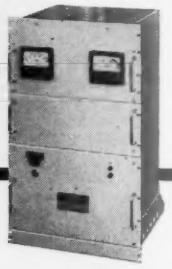

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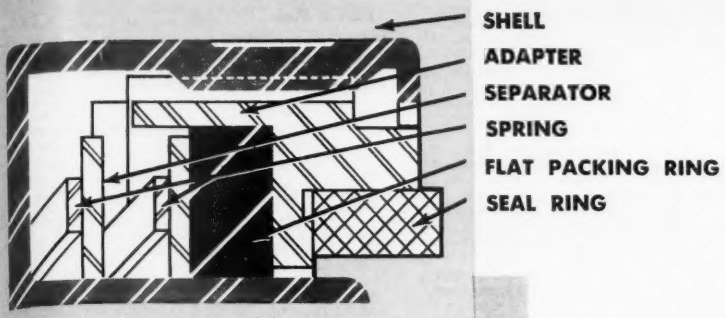

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Flugwerke in Honigwaben-Bauweise—Festigkeit und Herstellung. Geogres Ricard. *Luftfahrttechnik*, May 15, 1958, pp. 131–135. In German. Developmental survey of the sandwich construction research, with details on strength and weight aspects.

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New Techniques in Photoelasticity. Jarle Holen and E. E. Day. *Trend in Eng.*, Apr., 1958, pp. 10–16, 31. Investigation of the possibilities of fringe sharpening and fringe multiplication in photoelasticity.

Component Fatigue Testing. *Shorts Quart. Rev.*, Mar., 1958, pp. 13–15. Description of the main features of equipment used for component fatigue testing.

A Tensile Strut Testing Machine. H. Fessler. *RAeS J.*, July, 1958, p. 528.

An Investigation of Plastic Stress-Strain Relationships Using Grooved Tensile Specimens. J. P. Ellington. *J. Mech. & Phys. Solids*, July, 1958, pp. 276–281. Application of a method suggested by Hill for straining grooved tensile specimens to find the plastic potentials of thoroughly annealed copper and brass.

S Pomoshch'iu Radioaktivnykh Izotopov. G. Tafapol'skii. *Grashdanskaia Aviatsiia*, May, 1958, pp. 26, 27. In Russian. Evaluation of various methods for structural testing and maintenance inspection, and description of the gamma-radiation technique.

Hydrostatic Fuselage Pressure Fatigue Test Program Lockheed C-130A Hercules. D. S. Morcock. *Can. Aero. J.*, June, 1958, pp. 180–184. Discussion of the test procedure and description of the test set-up. The results of 10,000 simulated flights are presented.

Thermal Stress

Thermal Stresses in Design. I—Appraisal of Brittle Materials. II—Quantitative Techniques for Brittle Materials. S. S. Manson. *Mach. Des.*, June 12; 26, 1958, pp. 114–120; 99–103. Discussion on failure criteria, thermal shock in flat plates, and thermal-shock parameters in brittle materials. Methods for the measurement of thermal shock parameters and determination of short-duration thermal shock are presented.

Problemas Térmicos a Velocidades Supersónicas. III—Materiales y Estructuras. J. C. Gómez. *Rev. Aero.*, May, 1958, pp. 374–386. 21 refs. In Spanish. Discussion of thermal problems due to supersonic velocities, covering properties of light alloys at various temperatures and structural effects.

Simplified Equations for Transient Heat-Conduction to Insulated Metal Slab. J. H. Wiegand. *Jet Propulsion*, July, 1958, pp. 486, 487.

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Thermodynamics

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Tenth Quarterly Technical Status Report on Non-Stationary Surface Combustion Studies (Covering the Period from 15 Dec. to 15 Mar., 1958.) R. J. Magnus. *ADC Rep. 410/R-13/34*, 1958. 4 pp. USAF-sponsored investigation.

Separation of the Products of Cool Flame Oxidation of Propane. C. R. Yokley and R. E. Ferguson. *Comb. & Flame*, June, 1958, pp. 117–128. AFOSR-supported study applying the techniques of gas chromatography and low temperature, low-pressure distillation to the problem of the separation and isolation of the major products of cool flame oxidation of propane.

Spectrographic Investigation of a Cordite Flame at High Pressures. G. A. Heath. *Gt. Brit., RAE TN R.P.D. 161*, Dec., 1957. 22 pp. 17 refs. Measurements showing that the intense brightness of the final reaction zone is due to continuous radiation from carbon particles. From quantitative intensity measurements the temperature of the explosion zone at all pressures was found to be 2,350°K., which is less than the theoretical value assuming no loss of heat by radiation.

Effect of Pressure on Turbulent Burning Velocity. B. Fine. *Comb. & Flame*, June, 1958, pp. 109–116. 14 refs. Measurement of turbulent burning velocities for three fuel-oxidant systems over a range of pressures at nearly constant Reynolds Numbers. The results disagree with usual concepts of turbulent combustion.

Investigations on the Inflammability Ranges of Methane-Air and Butane-Air Mixtures Ignited by Electric Sparks. Gisèle Dalmai. *Comb. & Flame*, June, 1958, pp. 171–180. Discussion giving a tentative explanation of the two-lobed shape of the inflammability ranges of a number of hydrocarbons.

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Prismatic Fin with Non-Linear Heat Loss Analysed by Resistance Network and Iterative Analogue Computer. I. C. Hutcheon and D. B. Spalding. *Brit. J. Appl. Phys.*, May, 1958, pp. 185–191. Analysis of heat flow by natural convection from a fin of uniform conductivity and cross-sectional area, fixed at one end to a hot wall and immersed in a cooler fluid.

A Free Boundary Value Problem for the Heat Equation. W. L. Miranker. *Quart. Appl. Math.*, July, 1958, pp. 121–130. Presentation of a proof on the existence of a solution for a free boundary problem by demonstrating the existence of a solution to a nonlinear integrodifferential equation.

VTOL & STOL

VTOL Research Progress. *Shorts Quart. Rev.*, Mar., 1958, pp. 2–4. Discussion of SC.I gantry trials. A description of the structure and the function of the gantry is also made.

The Handling Qualities of VTOL Aircraft at Low Speed. P. F. Girard. *IAS Natl. Summer Meeting, Los Angeles, July 8–11, 1958, Preprint 843.* Members, $0.35; nonmembers, $0.75. 8 pp. Discussion of the major aspects of the principal handling qualities, piloting techniques, and human factors of VTOL aircraft in hovering and transitional flights.

Les Avions Breguet à Décollage Court. *L'Air*, June, 1958, p. 33. In French. Design and performance characteristics of the Breguet STOL aircraft.

Betrachtungen zum selbsttragenden Staustrahltriebwerk. Wilhelm Seibold. *Luftfahrttechnik*, May 15, 1958, pp. 141–143. In German. Evaluation of ram-jet propulsion systems, including the economic aspects, and discussion of their application to unfinned vehicles, as well as details on Coleopter systems.

Water-Based Aircraft

Flight Investigation of Some Airworthiness Problems of Civil Boat Seaplanes. J. Taylor, J. E. Allen, and A. G. Smith. *Gt. Brit., ARC R&M 3017* (Feb., 1955) 1958. 57 pp. 17 refs. BIS, New York, $3.60. Investigation of the measurement, control, and performance problems associated with seaplane take-off and initial climb.

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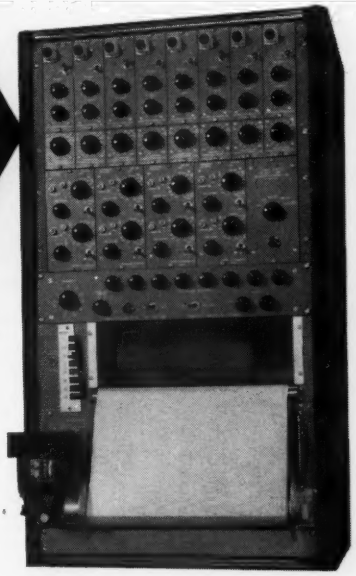

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THE FRONTIERS OF SPACE

Lockheed Missile Systems Division, recently honored at the first National Missile Industry Conference as "the organization that contributed most in the past year to the development of the art of missiles and astronautics," holds such important, long-term projects as: the Navy Polaris IRBM, Earth Satellite, Army Kingfisher target missile, and the Air Force X-7 ramjet test vehicle.

To carry out such complex projects, the frontiers of technology in all areas must be expanded. Responsible positions in our research and development laboratories and in our project organizations are available now for high-level engineers and scientists.

If you are experienced in physics, mathematics, chemistry or one of the engineering sciences, your inquiry is invited. Please write Research and Development Staff, Sunnyvale 3, California. (For the convenience of those living in the East and Midwest, offices are maintained at Suite 745, 405 Lexington Ave., New York 17, and at Suite 300, 840 N. Michigan Ave., Chicago 11.)

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FLIGHT IN THREE MEDIUMS

Several things set the Polaris apart from other outer space weapons in the ballistic missile category, for the Polaris program involves a wholly new concept of weaponry:

1. It will be dispatched from beneath the surface of the sea.
2. It will be radically smaller than currently developed land-launched missiles, yet its payload will be as effective and its range the same as other IRBMs.
3. It will be the first operational outer space missile to employ solid fuel as a propellant.
4. It will travel through three mediums in a single flight: water, air, outer space.
5. Its launching base—a submarine—is not fixed but a mobile vehicle.

OUTER SPACE PROGRAM

Very little can be said about the Earth Satellite program at this time except that its success will necessitate advancing the state of the art in all sciences.

The Earth Satellite Project is perhaps the most sophisticated outer space program to reach the "hardware" stage in the U.S. today.

TECHNOLOGY

ENEMY SIMULATOR

The Kingfisher is the nation's fastest target missile, developed for the Air Force and currently being manufactured for the Army to test the accuracy of our newest supersonic weapons.

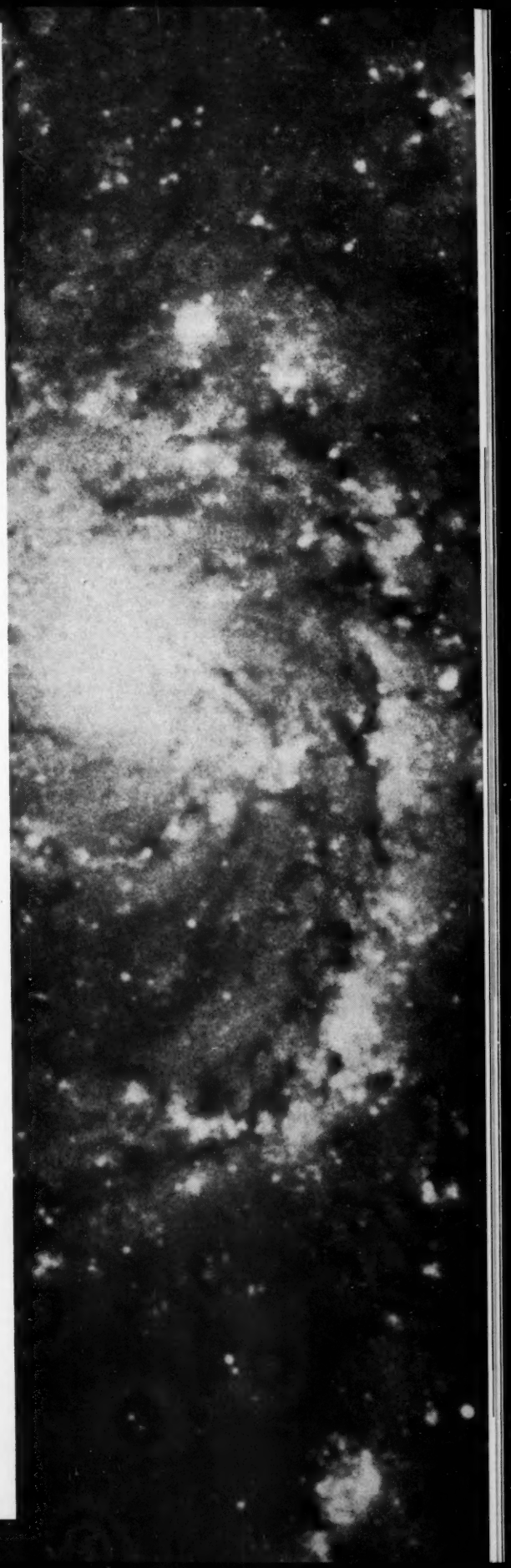
It is a ramjet target vehicle with Mach 2-plus capabilities. The Kingfisher not only has the speed to match the defensive missiles, but can also simulate a vast array of supersonic enemy missiles and airplanes attacking from great height. It is instrumented to score near misses and even theoretical hits without itself being destroyed.

It is recoverable from flight by parachute to be flown again, permitting weapon system evaluation to be conducted at greatly reduced cost.

Lockheed

MISSILE SYSTEMS DIVISION

SUNNYVALE • PALO ALTO • VAN NUYS • SANTA CRUZ
COOKE AIR FORCE BASE, CALIFORNIA
CAPE CANAVERAL, FLORIDA • ALAMOGORDO, NEW MEXICO



25 Convair 600 with G-E aft-fan CJ805-21 engines. American will lease the engines for the aircraft in both cases, the announcement said. Vice-President Willis Player has been named to head the Public Relations Department.

• **Beech Aircraft Corp.** reports that its MS 760 twin-jet business plane has become "the world's first turbojet aircraft to receive a CAA Type Certificate (No. 7A3)." Beech also announced the appointment of R. H. Owen to Manager of a newly formed Manufacturing Engineering Division at Wichita, Kan.

• **Bell Aircraft Corp.** reports that its automatic all-weather landing system has landed a Boeing 707 prototype without any pilot assistance. Stephen B. Elggren, a former Assistant Vice-President, has returned to the firm in the newly created post of Sales Manager, Niagara Frontier Division.

• **Boeing Airplane Co.** has formed a new unit in the Systems Management Office—designated the Advanced Project Proposal Team—headed by T. A. Wilson, formerly B-52 Engineering Project Manager, Seattle Division. He will plan, organize, and manage all activities dealing with preparation of a proposal for a new weapon system project, the firm said. D. E. Graves and I. W. Nealon have been named to assist him. The firm also announced that it has installed an IBM "random access method of accounting and control" (RAMAC) machine to help process orders for replacement parts for 707 and 720 aircraft.

• **Chance Vought Aircraft, Inc.,** has formed an Antisubmarine Warfare Engineering Task Force of seven groups headed by Vice-Adm. Harry Sanders, USN (Ret.). The groups are Systems Analysis, Detection, Missiles, Aircraft, Research and Development, Nuclear Propulsion, and Military Liaison. In addition, the company has also formed a new Electronics Department with James F. Reagan, former senior staff member, Ramo-Wooldridge Space Technology Laboratories, as Chief Engineer in charge of the department.

Chance Vought Aircraft calls its Crusader III (F8U-3) an all-weather "push-button" fighter capable of Mach 2 speed. Ventral fins on the lower fuselage cycle into a horizontal position for landings and take-offs, according to the firm. A Pratt & Whitney J-75 engine, 26,000 lbs. thrust with afterburner, powers the Navy fighter. This photo shows the aircraft carrying Sparrow III missiles.

• **Cornell Aeronautical Laboratory, Inc.,** has announced that it will investigate ways to advance techniques of photographic reconnaissance from space vehicles for the Air Force.

• **Douglas Aircraft Co., Inc.,** has announced plans for a $10 million wind-tunnel center, capable of testing vehicles designed to travel more than 8,000 m.p.h., on a 10-acre site on W. El Segundo Blvd., El Segundo, Calif. The firm also announced the appointment of W. G. Doran as Director of Materiel.

• **Edo Corp.** reports that its Airborne Loran for jet aircraft has been ordered by three additional airlines—Air France, Sabena, and KLM.

• **Fairchild Camera and Instrument Corp.** has announced the appointment of Charles Vickery as Manager, Los Angeles marketing office, Defense Products Division.

• **General Dynamics Corp.** . . . Convair Division has announced the appointment of R. B. Swanson as General Manager, Washington Office, and Assistant to Vice-President T. G. Lanphier, Jr. E. J. LeFevre has been named Manager, Air Force, in the Washington office. David Rowland was named Manager, Army, Washington office, and J. P. Shaw, current Manager, Navy, was given additional duties as Assistant General Manager, Washington. E. F. Jones, Assistant to the Vice-President, will direct Convair public relations in the East. In other changes, W. C. Keller has been assigned to the General Offices military relations staff, and Rex W. Warden, Chief Pilot at Convair's Palmdale facility, has been assigned to the office in Colorado Springs as Assistant to the Manager there. Three other Convair executives assigned to new positions are A. P. Higgins, Assistant to the Division Manager—military relations; J. H. Famme, Works Manager, Plant Two; and W. W. Fox, Assistant Chief Engineer. Harold N. May, General Purchasing Agent, has retired. . . . Stromberg-Carlson Division has announced the appointment of Brig. Gen. William L. Bayer, USA (Ret.), as Director, Planning, Electronics Division.

• **General Electric Co.** has appointed Robert D. Knies Manager, Manufacturing, Commercial Engine Operation, Evendale, Ohio. The company also announced that its J93 jet engine has been selected by the Air Force to power the North American B-70 and F-108.

• **General Precision Equipment Corp.** . . . General Precision Laboratory, Inc., has announced the appointment of Edward M. Lisowski as Sales Representative in Dayton, Ohio.

• **Grumman Aircraft Engineering Corp.** reports that an IBM 704 Data Processing System has been installed at its Bethpage,

North American's A3J Vigilante, shown on its first flight, is powered by two General Electric J79-2 engines of 15,000 lbs. thrust each. Approximate dimensions: wing span, 50 ft.; length, 70 ft.; height, 20 ft. The firm describes the plane as a supersonic all-weather carrier-based attack weapon system, which can deliver conventional and nuclear weapons at high or low altitudes. Bomb delivery is by rearward ejection from linear bomb bay, in effect a tunnel, running lengthwise in the aft section of the fuselage. The plane also uses boundary-layer control for low-speed landings.

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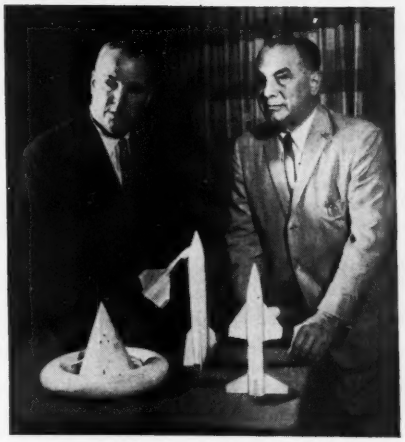
An invitation to senior scientists and engineers



A $14,000,000 R & D Center, housing 9 new laboratories, was revealed as core of Republic's $35,000,000 Research and Development Program at recent announcement by Mundy I. Peale, President, and Alexander Kartveli, Vice-President for Research and Development.

.... To join Republic Aviation's new $35 million Research and Development Program for spacecraft, missiles and advanced aircraft

In announcing Republic's $35 million research and development program, designed to arrive at major breakthroughs in the aviation industry's transition to astronautics, Mundy I. Peale, President, set the following objectives:

"...ACCELERATION OF PROJECTS ALREADY UNDER WAY AT REPUBLIC ON LUNAR PROGRAM FOR MANNED SPACE VEHICLES, AND MISSILES TO DESTROY ORBITING WEAPONS, AND INITIATION OF INVESTIGATIONS LEADING TO NEW CONCEPTS FOR INTERPLANETARY TRAVEL."

"...RADICAL NEW FAMILIES OF LONG-RANGE AIR-TO-AIR MISSILES AND AIR-TO-SURFACE BALLISTIC MISSILES FOR STRATEGIC AND TACTICAL AIRCRAFT."

"...VERTICAL TAKE-OFF FIGHTER-BOMBERS, HIGH-MACH FIGHTER-BOMBERS, AND SUPERSONIC TRANSPORTS."

Alexander Kartveli, Vice-President for Research and Development, emphasized that Republic's program "will not duplicate in any way investigatory work currently in progress elsewhere, but will stress novel concepts and new approaches to basic problems of missiles and space technology."

The program includes construction of a $14 million R & D center to house 9 new laboratories, and anticipates doubling the present research staff.

Senior men interested in the new possibilities created by a simultaneous exploration of all aspects of Flight Technology are invited to study the functions of the new laboratories for more detailed information:

SPACE ENVIRONMENTAL DEVELOPMENT LABORATORY
To simulate space flight conditions and test missile, satellite and spacecraft systems and components; investigate human engineering problems.

RE-ENTRY SIMULATION & AERODYNAMIC LABORATORY
To study hypersonic shock dynamics, real gas effects, heat transfer phenomena and magnetohydrodynamics.

MATERIALS DEVELOPMENT LABORATORY
Study effects of high velocity, temperature, and space environment on materials for spacecraft, missiles and advanced weapons.

GUIDANCE & CONTROL SYSTEM DEVELOPMENT LABORATORY
To develop and test guidance and control systems for spacecraft, missiles and aircraft.

ELECTRONICS DEVELOPMENT LABORATORY
Study and explore all problems connected with highly specialized, complex electronic systems required for advanced forms of spacecraft, missiles and aircraft.

ADVANCED FLUID SYSTEMS DEVELOPMENT LABORATORY
To develop and test fluid power systems for spacecraft and missiles capable of operation under extremely high temperature, high pressure conditions.

MANUFACTURING RESEARCH & DEVELOPMENT LABORATORIES
To develop advanced manufacturing processes and techniques for materials used in missiles and spacecraft. Laboratories for each of the following areas: *Non-Metallics, Metallics, Welding.*

Qualified men are invited to write directly to:
A. Kartveli, Vice President, Research and Development

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If you have comments or suggestions on any of the above features and departments . . . write to Mr. Allan Bernhardt, Editor. We want to work with YOU in developing tomorrow's news in the aero/space industry.

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N.Y., facility for use in designing and "test flying" future aircraft.

• **Walter Kidde & Co., Inc.,** reports that its Kidde CF_3Br fire-extinguishing system will be included in every turboprop commercial airliner now under construction in the United States.

• **Lear, Incorporated,** has opened its fourth regional headquarter field service facility at Westchester County Airport, White Plains, N.Y. . . . Grand Rapids Division has announced the following appointments: R. V. Paolucci, Contracts Marketing Manager; Robert N. Nielsen, Manager, West Coast Area Contracts office; G. Glenn Spence, Field Service Manager; and Charles J. Hafner, Corporate Field Service Manager (a newly created job).

• **Lockheed Aircraft Corp.** . . . Missile Systems Division has announced plans for a $7 million addition to the Sunnyvale, Calif., plant. The Division's Space Communications Laboratory also will get an 8,000-sq.ft. addition, nearly doubling its size, mainly for offices and to permit expansion of the existent building. Leslie D. Myers, Plant Engineer, Georgia Division, has been named Chief Engineer, Missile Systems Division. . . . Georgia Division has named Emil J. Docekal Plant Engineer.

• **Marquardt Aircraft Co.** reports it has proved that its XRJ59 ram-jet engine can fly three times around the world nonstop at altitudes of more than 14 miles and at higher-than-ever-before-achieved supersonic speeds. The firm based this conclusion on a continuous endurance test conducted at the Navy Ordnance Aerophysics Laboratory.

• **The Martin Co.** has announced selection of four major subcontractors for the Army's new solid-propellant Pershing missile system: Bendix Eclipse-Pioneer Division, inertial guidance stable platform and associated equipment; Bulova Watch Co., fusing and arming system; Thiokol Chemical Corp., propulsion system; and Thompson Products Accessories Division, transporter-erector-launcher.

• **McDonnell Aircraft Corporation's** new research laboratory and office at Berkeley, Mo., consists of 60,000 sq.ft. of office space and 120,000 sq.ft. of laboratory space.

• **North American Aviation, Inc.** . . . Autonetics Division has announced the appointment of Jesse Y. Bowman as Project Manager for the USAF Minuteman guidance and control system.

• **Northrop Aircraft, Inc.,** has elected Lt. Gen. Roger M. Ramey, USAF, (Ret.), a Corporate Vice-President to head the company's district offices. The Board of Directors also named Robert R. Miller (A) and Thomas V. Jones, senior Vice-Presidents with broad responsibilities in overall corporate management. Also elected Vice-Presidents were Richard R. Nolan and Irving Roth, both in the Northrop Division.

• **Pesco Products Division, Borg-Warner Corp.,** has named Donald R. Spotz Vice-President in charge of sales for all branches of this division and the Wooster Division.

• **The Ramo-Wooldridge Corp.** has named four vice-presidents to new re-

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sponsibilities: Ralph P. Johnson, in charge of the General Electronics Group of Divisions; Burton F. Miller, director, advanced systems planning; Milton E. Mohr, Engineering, responsible for the Control Systems Division, Communications Division, and the Electronic Instrumentation Co.; and Irwin A. Binder, Manufacturing, responsible for all Denver and Los Angeles activities of the Manufacturing Division. . . . Pacific Semiconductors, Inc., reports the election of Warren B. Hayes as Vice-President. He will continue to direct Engineering, Manufacturing, and Sales Department activities.

• **Republic Aviation Corporation's** recently announced expansion plans also call for the addition of scientists and engineers to the engineering, development, and scientific research staffs. New R&D labs will be set up for space environmental development, re-entry simulation and aerodynamic development, materials development, electronics development, guidance and control system development, and advanced fluid systems development. Three process laboratories will aid manufacturing R&D. In the missile area, the company will concentrate on new and novel concepts for strategic, tactical, and air defense missiles. . . . Helicopter Division reports that Edward D. Jergens has joined the firm as a pilot.

• **Ryan Aeronautical Co.** reports that it has acquired an additional 11 acres at its Torrance, Calif., Division, adjacent to Torrance Municipal Airport.

• **Socony Mobil Oil Co., Inc.,** announced that it is completing arrangements to supply aircraft at the new Leonardo da Vinci Airport under construction outside Rome and that more than 600 airports in 70 countries and territories are now equipped to supply aircraft with Mobil aviation products.

• **R. Dixon Speas Associates** have announced the appointment of Harry Schmidt as Engineering Consultant. Formerly an Engineering Test Pilot for Pratt & Whitney Aircraft, he will be responsible for Flight Operation Studies and Operating Cost Analyses for turbojet and turboprop aircraft.

• **Sperry Gyroscope Co., Division of Sperry Rand Corp.,** has announced through its newly created Field Engineering Division a new program said to offer rapid delivery of replacements for flight control, instrument, compass, engine analyzer, and other airborne equipment, at fixed prices.

• **Standard Oil Co. (Indiana),** has announced that its research laboratories at Seymour are being enlarged for the second time to increase its program in solid fuels development.

• **Stanley Aviation Corp.** announced that Austin Marquis has joined its staff as Manager of Contracts and Commercial Sales. He will supervise the administration of Government contracts and assume responsibility for the sale of commercial products.

• **Thiokol Chemical Corp.,** Callery Chemical Co., and General Motors Corp. have announced an agreement to pool their technology in a concentrated effort to advance overall astronautical development without restricting individual research, sales, or production programs.

• **Thompson Products, Inc.,** has opened an office in Washington at the National Grange Building on Lafayette Square. Frank A. Flower has been appointed Manager and Arthur R. Christie Senior Consultant in the new office.

• **United Air Lines, Inc.,** reports that it has ordered a $16 million passenger reservations system—said to be the largest interconnected electronic data processing system ever to be built for any industry.

• **United Aircraft Corp.** . . . Sikorsky Aircraft Division has moved into its new 500,000-sq.ft. engineering wing at Stratford, Conn.

• **Vard, Inc.,** announced that it will produce drive systems consisting of main transmissions, fan-cooling gear drives, and tail-rotor gear drives for Hiller Helicopters.

• **Vertol Aircraft Corp.** has announced the election of Vice-President Felix A. Kalinski to the Board of Directors. Mrs. Peg C. Caole has been appointed Manager, Public Relations. The firm also announced the first transition flight of its Model 76 tiltwing VTOL.

• **Westinghouse Electric Corp.** has announced the establishment of its Defense Products Headquarters at 1000 Connecticut Ave., N.W., Suite 1004, Washington 6, D.C. The division also has opened a sales office at Roosevelt Field, 600 Old Country Rd., Garden City, N.Y.

IAS News — IAS Sections

San Antonio Section

USAF Studies Man as Space Animal

"Newest Developments in Space Flight and Experimental Studies in Sealed Cabins" were discussed by **Lt. Col. G. R. Steinkamp, G. T. Hauty,** and **Dr. W. R. Hawkins** on June 24. The speakers were from the Air Force School of Aviation Medicine.

Colonel Steinkamp, Chief, Department of Space Medicine, explained the mission of the school. Dr. Hawkins spoke on the physiological effects experienced by crew members in sealed cabins and described plans for experimental flights. The talk included a documentary film on a simulated 7-day space flight.

Dr. Hauty, using slides, discussed psychological effects and findings on this space flight experiment.

ROBERT A. PERRY, *Secretary*

St. Louis Section

Fred H. Roever Elected Chairman

A new slate of officers was elected for the 1958–1959 term. They are F. H. Roever, Chairman; A. D. Massey, Vice-Chairman; T. M. Bellan, Recording Secretary; R. E. Rolfe, Corresponding Secretary; and O. B. McBee, Treasurer.

Named to the Advisory Board were T. W. Collins, Jr., J. F. Yardley, Albert Utsch, and L. I. Mirowitz.

Tulsa Section

Missile Scientist Favors Soaring

W. B. Klemperer, Missiles Division, Douglas Aircraft Co., discussed **"Soaring Flight—Past, Present, and Future"** at the June 17 meeting. He described several of his personal experiences in gliding, dating from World War I to the present time.

New officers for the 1958–1959 term are Charles E. Barton, Chairman; Jack W. James, Vice-Chairman; Peter C. Johnson, Corresponding Secretary; Allan M. McCaskill, Recording Secretary; and Bruce D. Olson, Treasurer.

BRUCE D OLSON
Recording Secretary

Washington Section

New Section Officers Elected for 1958–1959

Paul E. Garber, Head Curator, National Air Museum, discussed **"The History of Aviation"** at the May 13 meeting.

Using slides, he traced the story of aviation from mythological conceptions to supersonic aircraft and missiles.

New officers for 1958–1959 were announced as follows: G. L. Desmond, Chairman; B. C. Myers, II, Vice-Chairman; Quinten J. Goss, Secretary; and Richard de Callies, Treasurer.

Guests at the meeting were four high school winners of science fair awards and their school advisers.

F. J. SWEET, *Secretary*

Wichita Section

M. F. Vanik Elected Chairman

Newly elected officers for the 1958–1959 term are Milford F. Vanik, Chairman; Howard W. Smith, Vice-Chairman; Everette L. Cook, Secretary; and Harry R. Clements, Treasurer.

Change of Address

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A comprehensive summary of the fundamentals involved in the propulsion, aerodynamics, guidance, and control of missiles and space vehicles. Stresses science and engineering principles for estimating performance, and covers design characteristics and functions of component parts of missiles and weapons systems in general. One of the Wiley Books in Space Technology.
1958. Approx. 586 pages. Illus. Probably $11.75

SURVEYS IN APPLIED MATHEMATICS

Initiated by the Editorial Office of *Applied Mechanics Reviews*. An up-to-date review of recent mathematical progress.

2. Vol. I—ELASTICITY AND PLASTICITY
   By J. N. GOODIER and P. G. HODGE, Jr. 1958. 152 pages. $6.25
3. Vol. II—DYNAMICS AND NONLINEAR MECHANICS
   By E. LEIMANIS and N. MINORSKY. 1958. 206 pages. $7.75
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   By L. BERS. 1958. 164 pages. $7.75
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   By I. KAPLANSKY, E. HEWITT, M. HALL, JR., and R. FORTET. 1958. 243 pages. $9.00
6. Vol. V—NUMERICAL ANALYSIS AND PARTIAL DIFFERENTIAL EQUATIONS. By G. E. FORSYTHE and P. C. ROSENBLOOM. 1958. Approx. 204 pages. $7.50

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AERODYNAMICS

Natural Aerodynamics. R. C. Scorer. (International Series of Monographs on Aeronautical Sciences and Space Flight, Division II, Aerodynamics, Vol. I) London, Paris, New York, Los Angeles, Pergamon Press, 1958. 312 pp., illus., diagrs. $9.00.

In this study of the physical principles and processes of fluid motion, the author explains the relationship between the forces and the motion of any fluid with special reference to the behavior of the air in which we live. The treatment is elementary and is intended primarily to stimulate discussion among students of fluid mechanics, yet certain chapters will prove useful to mathematicians and experimentalists in natural aerodynamic research. The topics discussed include inertia forces, motion on a rotating earth, vorticity and viscosity, boundary layers, wakes and turbulence, buoyant convection, plumes and jets, air waves, and clouds and fall-out.

Mr. Scorer, who is Reader in Applied Mathematics, Imperial College, London, closes his book with a discussion of the philosophy of method employed by mathematicians, physicists, and geographers in their examination of natural phenomena.

AIR TRANSPORTATION

International Flight Information Manual, Vol. 8. U.S. Civil Aeronautics Administration. Washington, Supt. of Documents, February, 1958. 112 pp. $0.50.

A complement to International NOTAMS, this annual tabulates foreign international aerodromes and aerodromes of entry, as well as prohibited areas, flight corridors, restrictions, and regulations. Also included are U.S. Aeronautical Telecommunications Services for use in international flights.

CHEMICAL ENGINEERING

Chemical Engineering Practice, Vol. 4, Fluid State. Herbert W. Cremer, General Editor; Trefor Davies, Managing Editor. London, Butterworths Scientific Publications; New York, Academic Press, Inc., 1957. 623 pp., illus., diagrs., tables. $17.50.

Contents: *Thermodynamic Properties of Physical Symptoms*, R. F. Strickland-Constable: Summary of First and Second Laws of Thermodynamics, The Chemical Potential as a Criterion of Equilibrium, General Thermodynamic Relationships, Properties of Single Substances, Properties of Mixtures, Available Work—Sum and Difference Properties, Fluid Flow. *The Transport Properties of Fluids*, N. L. Franklin and F. H. Cass: Fluid Statics, The Flow of Viscous Fluids, Turbulence, Flow within Tubes and Ducts, Flow around Objects, Compressible Fluids. *Measurement of Process Variables*, Allan Pollard and T. G. Carruthers. Index.

DICTIONARIES

Dictionary of Military Terms: English-German, German-English. Friedrich Krollmann. Berlin-Schöneberg, Langenscheidt KG.; New York, Philosophical Library, 1957. 769 pp. $10.

Owing to radical alterations in the structure equipment of modern armed forces, the language of the military has undergone a great deal of change during the last decade. In this addition to the internationally known Langenscheidt series of dictionaries, the author has tried to cover the military terminology of today insofar as this could be achieved in a pocket-size volume. Some 6,000 terms are presented. Additional features are a table of common British and American abbreviations, appendixes devoted to monetary units and phonetic alphabets, tables of interrelation of units of measurements, and equivalent ranks of the German, American, and British forces.

ELECTRONICS

Microwave Transmission Design Data. Theodore Moreno. (Reprint of 1948 Edition.) New York, Dover Publications, Inc., 1958. 248 pp., diagrs. $1.50.

ENGINEERING

Recent Advances in the Engineering Sciences, Their Impact on Engineering Education. Proceedings of Conference on Science and Technology for Deans of Engineering, September 9–12, 1957, Purdue University, Lafayette, Ind. New York, McGraw-Hill Book Co., Inc., 1958. 257 pp., illus., diagrs., tables. $4.75.

Contents: Automation and Automatic Control: A Survey of the Field, John G. Truxal; The Impact on Engineering Education, Gordon S. Brown. Operations Research and Systems Engineering: A Survey of the Field, Harry H. Goode; The Impact on Engineering Education, D. G. Malcolm. Administrative Problems in Engineering: Recent Trends in the Cost of Engineering Education, R. W. Kettler. Thermodynamics: A Survey of the Field, Myron Tribus; The Impact on Engineering Education, Newman A. Hall. Mass, Momentum, and Heat Transfer: A Survey of the Field, E. R. G. Eckert; The Impact on Engineering Education, R. B. Bird. Nuclear Engineering: A Survey of the Field, Stuart McLain; The Impact on Engineering Education, Henry J. Gomberg. Solid State Physics and Engineering Materials: A Survey of The Field, J. E. Goldman; The Impact on Engineering Education, Glenn Murphy. Computer Development and Application: A Survey of the Field, Samuel Alexander; The Impact on Engineering Education, J. P. Nash.

INSTRUMENTS

Electronic Measuring Instruments. E. W. H. Banner. 2nd Rev. Ed. New York, The Macmillan Co., 1958. 496 pp., illus., diagrs., tables. $7.95.

This survey of the principles of electronic instruments and their principal types and component devices includes descriptions of vacuum and cathode-ray tubes; industrial, scientific, and medical measuring instruments; and radiation measurements. New features include special reliability and subminiature tubes, junction-type transistors, thermovariable resistors, waveform error, multiwave voltmeters, flying-spot microscopes, portable radiation pyrometers, metal rectifier instruments, survey and combination meters, special transducer systems, palladium leak detectors, and electronic tachometers. The author has endeavored to comply with British standard terminology, symbols, and spelling of technical terms and quotes British Standards and Codes of Practice, where relevant.

MATERIALS

Causes and Prevention of Corrosion in Aircraft. T. C. E. Tringham. London, Sir Isaac Pitman & Sons, Ltd.; New York, Pitman Publishing Corp., 1958. 124 pp., illus., diagrs., tables. $5.75.

This book was written to afford persons in the aircraft industry an opportunity to acquire a practical knowledge of the many causes of corrosion and the measures that should be taken to prevent its incidence. It does not purport to be a learned treatise on the mechanics of corrosion, but rather a simple outline of a problem which must be clearly understood by those engaged in aircraft construction and maintenance.

Contents: (1) An Introduction to Corrosion. (2) Sources of Corrosion in the Manufacturing Processes. (3) Storage Procedures. (4) The Aircraft in Service. (5) Causes and Prevention of Corrosion in Engines and their Associated Components. (6) Corrosion in Electrical Equipment. (7) Cleaning Metal Prior to Electroplating. (8) The Electroplating Processes. (9) Anodic Oxidation of Aluminium and Chormating of Magnesium. (10) The Metallizing Processes. (11) The Pre-Treatments of Metal Prior to Painting. (12) Paints, Enamels, Varnishes and Resins for Protecting Aircraft Components. (13) Non-Destructive Examination. (14) Aircraft Salvage. Appendix 1, Comparison of Hydrometer Degrees, Baumé and Twaddell, with Specific Gravities. Appendix 2, Comparison of Fahrenheit and Centigrade Scales. Bibliography. Index.

MATHEMATICS

Mathematics of Physics and Modern Engineering. I. S. Sokolnikoff and R. M. Redheffer. New York, McGraw-Hill Book Co., Inc., 1958. 810 pp., diagrs., tables. $9.50.

A working course in calculus is the only technical prerequisite for this introduction to applied mathematics, which contains what the authors believe to be the minimum mathematical equipment of a scientific engineer. The nine chapters of text, complete with themselves and virtually independent of each other, deal with ordinary differential equations, infinite series, functions of several variables, algebra and geometry of vectors —matrices, vector field theory, partial differential equations, the complex variable, probability, and numerical analysis. Some of the topics treated include the use of complex forms of solutions for linear differential equations, mean and pointwise convergence of a Fourier series, the Poisson and Helmholtz equations, a modern treatment of probability and relative frequency, effective uses of complex variables in boundary-layer problems, a discussion of Dirac's function in connection with the Laplace transform, and the relation between differential and difference equations.

Sokolnikoff, Professor of Mathematics, and Redheffer, Associate Professor of Mathematics, both at the University of California, have written the book primarily as a text for students of physical sciences but have also included a large amount of material of direct interest to practicing engineers.

Calculus of Variations and Its Applications. Proceedings of the 8th Symposium in Applied Mathematics of the American Mathematical Society, Held at the University of Chicago, April 12–13, 1956; Cosponsored by the Office of Ordnance Research, U.S. Army. Lawrence M. Graves, Editor. (Proceedings of Symposia in Applied Mathematics, Vol. 8.) New York, McGraw-Hill Book Co., Inc., 1958. 153 pp. $7.50.

Contents: On Variational Principles in Elasticity, Eric Reissner. Variational Principles in the Mathematical Theory of Plasticity, D. C. Drucker. Discussion of D. C. Drucker's Paper, "Variational Principles in the Mathematical Theory of Plasticity," P. G. Hodge, Jr. A Geometrical Theory of Diffraction, Joseph B. Keller. Upper and Lower Bounds for Eigenvalues, J. B. Diaz. Stationary Principles for Forced Vibrations in Elasticity and Electromagnetism, J. L. Synge. A Variational Computation Method for Forced-Vibration Problems, H. F. Weinberger. Applications of Variational Methods in the Theory of Conformal Mapping, M. M. Schiffer. Dynamic Programming and Its Application to Variational Problems in Mathematical Economics, Richard Bellman. Variational Methods in Hydrodynamics, S. Chandrasekhar. Some Applications of Functional Analysis to the Calculus of Variations, E. H. Rothe. Index.

Operational Mathematics. Ruel V. Churchill. 2nd Ed. New York, McGraw-Hill Book Co., Inc., 1958. 337 pp., diagrs. $7.00.

This textbook on the theory and applications of Laplace transforms and other integral transforms is an extensive revision of *Modern Operational Mathematics in Engineering*, published in 1944. The operational properties of the Laplace transformation are followed in a natural manner by the operational mathematics for various Fourier transformations and their generalizations and by the theory and applications of eigenvalue problems. A procedure is described for selecting the proper operational mathematics to solve a given boundary value problem. The applications are chiefly to problems in engineering and physics that involve differential equations, with emphasis on boundary value problems in partial differential equations. Discussions include problems in vibrating mechanical systems, electric circuits, and servomechanisms, involving systems of ordinary differential equations.

The author, who is Professor of Mathematics, University of Michigan, has written the book for students of mathematics, engineering, physics, and other sciences, whose mathematical background has reached the level of advanced calculus.

Mathematical Tables of Elementary and Some Higher Mathematical Functions. Herbert Bristol Dwight. 2nd Ed. (Reprint of 1941 Ed.) New York, Dover Publications, Inc., 1958. 217 pp. tables. $1.75.

Differential Equations. Forest Ray Moulton. (Reprint of 1930 Edition.) New York Dover Publications, Inc., 1958. 395 pp. $2.00.

History of Mathematics. Vol. 1, General Survey of the History of Elementary Mathematics; Vol. 2, Special Topics of Elementary Mathematics. David Eugene Smith. (Reprint of 1953 Edition.) New York, Dover Publications, Inc., 1958. Vol. 1, 596 pp., illus., diagrs.; Vol. 2, 725 pp., illus., diagrs. $5.00 the set.

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METEOROLOGY

Proceedings of the Polar Atmosphere Symposium, Part I, Meteorology Section; Held at Oslo, July 2–8, 1956. North Atlantiic Treaty Organization, Advisory Group for Aeronautical Research and Development (NATO, AGARD). *Journal of Atmospheric and Terrestrial Physics, Special Supplement*, 1957. London, Paris, New York, Los Angeles, Pergamon Press, 1958. 341 pp., illus., diagrs., tables. $22.50.

Contents: Opening Address, F. L. Wattendorf. Introduction Speech, H. U. Sverdrup.

Section I. Arctic Geography and Climate, F. Kenneth Hare. Similarities and Contrasts between the Arctic and Antarctic Marine Climates, R. M. Holcombe. The Recent Variations of the Climate at the Norwegian Arctic Stations, Th. Hesselberg and T. Werner Johannessen. A Brief Review of Research in Arctic Meterology, A. D. Belmont. Discussion, 2 July 1956.

Section II. The General Circulation of the Lower Troposphere over Arctic Regions and its Relation to the Circulation Elsewhere, Jerome Namias. Recent Studies on the Arctic Troposphere and its Teleconnections, H. Flohn and G. Seidel. Winds and Temperatures in the Arctic Stratosphere, H. Wexler and W. B. Moreland. The Arctic Winter Stratospheric Jet Stream (Abstract), W. L. Godson. The Problem of the Maintenance of the Low-Level Anticyclonic Circulation in the Arctic, R. Fjørtoft. Discussion, 3 July 1956.

Section III. The Role of Tropospheric Cold-Air Poles and of Stratospheric High-Pressure Centers in the Arctic Weather, R. Scherhag. Arctic Weather-Forecasting Problems of the Air Weather Service, R. D. Fletcher. Arctic Weather Analysis, R. J. Reed. The Quantitative Representation of the North Polar Pressure Field, F. Kenneth Hare. Discussion, 4 July 1956. An Empirical Method of Forecasting 24-Hour Movement and Change of Intensity of Sub-Arctic North Atlantic Cyclones (Abstract), J. J. George, P. M. Wolff, and W. L. Somervell, Jr.

Section IV. Solar Radiation Measurements in the Arctic Ocean, S. Fritz. Long-Wave Radiation and Turbulent Heat Transfer in the Antarctic Winter and the Development of Surface Inversions, G. H. Liljequist. On the "Arctic Whiteout," S. Fritz. On the Relation Between Meterological Conditions and Total Amount of Ozone over Tromsö, H. Johansen. Visual Range in the Polar Regions with Particular Reference to the Alaskan Arctic, J. Murray Mitchell, Jr. Some Problems of Meterological Observing in Polar Regions, N. J. Schumacher. Lower Tropospheric Inversions at Ice Island T-3, A. D. Belmont. Current Status of Sea Ice Reconnaissance and Forecasting for the American Arctic, C. C. Bates. Meterological Conditions and the Associated Sea Ice Distribution in the Chuckchi Sea During the Summer of 1955, J. W. Winchester and C. C. Bates. Discussion, 6 July 1956.

POWER PLANTS

Aircraft and Missile Propulsion; Vol. 1, Thermodynamics of Fluid Flow and Application to Propulsion Engines. M. J. Zucrow. New York, John Wiley & Sons, Inc., 1958. 538 pp., diagrs., tables. $11.50.

The present book is the first of a three-volume work which discusses the underlying principles of the technology pertinent to the following propulsion engines: the turboprop, the turbojet, the ram-jet, the liquid-propellant rocket, and the solid-propellant rocket. *Volume II* will be devoted to the analysis of the cycles and the performance characteristics of these engines and *Volume III* will deal with their components. The series is intended primarily for engineering students and for those engineers who, though not specialists in propulsion, are desirous of an understanding of the functioning and operating characteristics of the engines employed in propelling high-speed aircraft and missiles.

As its subtitle indicates, *Volume I* is concerned with the thermodynamics of fluid flow and its application to propulsion engines. Beginning with a review of fundamental principles and the general characteristics of propulsion systems, the author proceeds to a discussion of the thermodynamics of compressible fluid flow, flow through nozzles, and diffusers. A large number of illustrative problems are worked completely, and the book closes with the tables of functions required for solving these problems, thus making the book practically self-contained.

Dr. Zucrow has served on numerous Governmental advisory panels and committees concerned with missile and propulsion research and is presently Professor of Gas Turbines and Jet Propulsion, Purdue University.

Jet Propulsion. Walter J. Hesse. New York, Pitman Publishing Corp., 1958. 567 pp., illus., diagrs., tables. $9.75.

The purpose of the book, which evolved from courses given at the Naval Air Test Center, Patuxent River, Md., is to present a balanced treatment of the subject of jet propulsion in which the chief emphasis is placed on principles of operation, and concepts are developed from fundamental engineering laws rather than from an equation standpoint. A working knowledge of calculus, physics, thermodynamics, and aerodynamics or fluid mechanics is required to comprehend the

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material in the text, which also contains a wide selection of assignment problems, solutions, and pertinent appendixes.

The author is Chief of Advanced Weapons Systems, Planning and Analysis, Chance Vought Aircraft, Inc., and Graduate Lecturer, Southern Methodist University.

Contents: Symbols and Units. (1) Review of Principal Definitions, Concepts, and Basic Physical Laws. (2) Principle of Jet Propulsion and Engine Classification. (3) Aerothermodynamics of Steady, One-Dimensional Isentropic Compressible Flow. (4) Compressible Flow in Constant-Area Ducts and the Thermodynamics of Shock Waves. (5) Diffuser and Nozzle Flow with Friction. (6) Energy Transfer in Turbo-Machinery. (7) Centrifugal Compressors. (8) Axial-Flow Compressors. (9) Combustion Chambers, Fuels, and Controls. (10) Gas Turbines. (11) The Turbojet Engine. (12) Thrust Augmentation of the Turbojet Engine. (13) The Turboprop Engine. (14) High Flight Mach Number Air-Breathing Engines. (15) The Rocket Engine. Appendixes. Index.

SAFETY

Handbook for Aircraft Accident Investigators. Prepared by the U.S. Naval Aviation Safety Center and Issued by the Office of the Chief of Naval Operations. (NAVAER 00-80T-67.) Washington, Sup. of Documents, 1957. 120 pp., illus., diagrs. $1.50.

The objective of this manual is to provide the aircraft accident investigator with sufficient information to conduct a comprehensive, educated, and thorough accident investigation with a view toward reducing erroneous conclusions. The essentials of good investigation are explained, including preaccident planning, organization, and procedures at the scene of an accident. Wreckage recovery and examination of damaged parts are thoroughly explored, and the importance of witnesses, records, and aeromedical analysis is pointed up. In addition, the manual contains numerous appendixes delineating physical equipment and methods employed in accident investigation and a small number of references to other literature useful to the investigator.

SPACE TRAVEL

Space Flight; Satellites, Spaceships, Space Stations, and Space Travel Explained. Carsbie C. Adams. With the Collaboration of Frederick I. Ordway, III, Heyward E. Canney, Jr., and Ronald C. Wakeford. New York, McGraw-Hill Book Co., Inc., 1958. 373 pp., illus., diagrs. $6.50.

Dr. Adams's book, which begins with a historical review of both the mental and the physical evolution of space flight as it may be said to have developed in the past 4,000 years, is designed to give the layman, the student, and the practicing engineer and scientist a well-rounded account of (1) the history and background of the astronautical sciences, (2) the many subsidiary fields that compose these sciences, and (3) detailed information on many of the most important world-wide developments of astronautical significance. The book is further intended to offer broad coverage of introductory space flight material, to assess the present state of the art, and to present some glimpse of the future potential of astronautics.

The author is President, National Research and Development Corporation.

STRUCTURES

Design of Circular Cylindrical Shells. Ivar Holand. (Norges Tekniske Vitenskapsakademi, Series 2, No. 3.) Oslo, Oslo University Press, 1957. 253 pp., tables.

The scope of this work, which deals with the design of circular cylindrical shells based on the mathematical theory of elasticity, embraces improvement of the mathematical methods leading from the three simultaneous partial differential equations of Flügge to the actual forces and displacements in the shell predicted by the theory of elasticity. Beginning with the basic theory as expressed by the differential equations of the circular cylindrical shell, the author proceeds to discuss in subsequent chapters such topics as forces and displacements in terms of a stress function, edge disturbances from the straight edge and from the curved edge, particular integrals, and edge members at the straight edge. Numerical examples are supplied in Chapter 7.

The studies and investigations leading up to the book were made during a 2-year stay at the Technical University on a scholarship granted by the University.

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STRUCTURES: Experience in analysis of systems or structures for optimum load paths, methods of analysis, and most efficient and practical structure design consistent with applicable specifications and environment.

DYNAMICS: Experience in analysis of systems or structures subjected to shock and/or vibratory loads. The evaluation of structures will often require use of differential equations and a knowledge of static and dynamic properties of various metals.

Sandia Corporation, located in Albuquerque, N.M., offers excellent working and living conditions and generous employee benefits, including liberal holidays and vacations, retirement and insurance plans, and graduate educational aid program.

Write to Staff Employment
Section 514

SANDIA CORPORATION

ALBUQUERQUE, NEW MEXICO

MARQUARDT

Professional Personnel Requisition

Group Leader—

INTERNAL AERODYNAMICS

Responsible for analysis of internal flow problems in support of hypersonic ramjet engine research program. Will also be responsible for development of proper inlet design criteria as well as experimental investigations of inlet systems at hypersonic speeds. Requires extensive analytical and experimental inlet flow experience.

Position is in ASTRO, Marquardt's research division. Small, responsible group. Excellent individual recognition.

Requires degree plus 7 years experience. Needs strong technical and leadership ability.

Contact **Jim Dale, Manager**
Professional Personnel
Marquardt Aircraft Co.
16553 Saticoy Street
Van Nuys, California

marquardt AIRCRAFT CO.

VAN NUYS, CALIFORNIA OGDEN, UTAH

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Personnel Opportunities

This section is for the use of individual members of the Institute seeking new connections and eligible organizations offering employment to specialists in the aero/space industry. Any member or eligible organization may have requirements listed without charge by writing to the Secretary of the Institute.

Wanted

Engineers (Aeronautical, Electrical, Electronic, Industrial, General, Mechanical, and Power Plant), **Electronic Scientists, Metallurgists, Physicists, Technologists**—Vacancies exist for professional personnel in the above positions. Starting salaries range from $4,490 to $8,810 per annum. The Naval Air Material Center is currently engaged in an extensive program of aeronautical research, development, experimentation, and test operations for the advancement of Naval aviation. Personnel are needed for work on projects involving modification, overhauling, and testing of aeronautical equipment, materials, accessories, power plants, and launching and arresting devices, and for modification and structural testing of aircraft. Personnel are also needed for work involving the basic design of catapults, launchers, arresting gear and their component parts; test and development work at shore stations and on board U.S. Navy ships; evaluation of new equipment and establishment of performance parameters and applied research on the many problems relevant to this field.

Interested persons should file an Application for Federal Employment, Standard Form 57, with the Industrial Relations Department, Naval Air Material Center, Naval Base, Philadelphia 12, Pa. Applications may be obtained from the above address, or information as to where they are available may be obtained from any first- or second-class post office.

Engineers—Engineers and scientists required at all levels for ARDC. Locations in California, New York, Washington, D.C., Ohio, New Mexico, and Massachusetts. Write to Headquarters, Air Research and Development Command, Attn.: RDSPCE, Andrews Air Force Base, Washington 25, D.C.

Jet-Engine Exhaust Nozzle Mechanical Design Specialist—Responsible for establishing and maintaining the mechanical design and development of the exhaust nozzle for specific engine project jet engines and derivative models manufactured in experimental, prototype, and production quantities to meet established objectives of performance, weight, critical materials, dependability, cost, timing, application, and producibility. Includes technical and functional guidance and functional leadership for designated positions. Requires B.S.M.E. from accredited college, preferably with graduate work in heat transfer and stress nozzles and at least 3 years' general engineering experience dealing with mechanism and machine design. Starting salary ranges $7,740 to $9,000.

Many positions also open in other phases of advanced propulsion development, including controls systems, high energy fuels, lubrication systems and insulation, stator engineering for assigned aircraft, test programing, and implementation, etc. Address: Mark Elwood, Jet Engine Department AS-1, General Electric Co., Cincinnati 15, Ohio.

Senior Aeroelasticity Engineer—Evaluate new airplane and missile designs from an aeroelastic standpoint; contribute to the aeroelastic design of production weapon systems, including considerations of vibration, flutter, and static aeroelasticity. **Senior Dynamic Test Engineer**—Assume complete responsibility for major experimental programs including ground vibration testing of complete weapon systems, design and testing of complex aeroelastic models, and flight flutter testing of advanced weapon systems. **Acoustic Specialist**—Required to predict environmental vibration and acoustical levels in and around the aircraft and to predict the response of equipment and aircraft structure to these inputs. Design of vibration isolators and acoustic insulation. You will be supported in these activities by well-trained mathematicians and engineers. Send replies to R. J. Theibert, Engineering Personnel, North American Aviation, Inc., 4300 East Fifth Ave., Columbus 16, Ohio.

Meteorologist—(Nuclear Hazards Experience Preferred.) To assist in preparing analytical predictions of the diffusion and deposition of atmospheric contaminants; to assist in selecting new sites for nuclear development projects; to correlate results of field diffusion and deposition experiments with the analytical methods used (3–6 years' experience required). **Reactor Controls Engineer**—For analysis of reactor kinetics and overall nuclear power-plant control systems; for integration of reactor control system into overall weapon system controls (5 years' experience required). **Shielding Engineer**—For advanced studies and analyses on mobile shields, shield design, optimization and testing (5 years' experience required). **Thermodynamicist**—Heat transfer and fluid flow analysis for reactor systems (3 years' experience required). Send résumé to R. S. Stiff, Engineering Personnel, Chance Vought Aircraft, P.O. Box 5907, Dallas, Tex.

Aircraft Air Conditioning & Pneumatics—Degree in Mechanical or Aeronautical Engineering with 5 years' experience in aircraft air conditioning, anti-icing and/or low-pressure pneumatic systems. Assignments entail development of specifications of new aircraft systems, analysis of system and component operation, and correction of problems by design changes or revision of operating, maintenance, and overhaul procedures. **Test Equipment Development**—Degree in Electrical Engineering with 3 years' experience in the design of electrical and electronic test equipment for aircraft components and systems. Experience in design of hydraulic and pneumatic test equipment also desirable. Responsibilities entail design and/or preparation of specifications for various types of test equipment and close coordination with equipment manufacturers on development and procurement of this equipment. **Aircraft Interiors**—Aeronautical degree with 5 years' minimum experience in design of passenger and cargo aircraft interiors. Structural experience desired. This position entails responsibility for development, evaluation, design, and modification of aircraft interiors and related components. Send replies to J. W. Mole, Staff Manager, Employee Selection, American Airlines, Inc., 910 South Boston Ave., Tulsa 19, Okla.

Engineers—The Gruen Applied Science Laboratories, Inc., has openings for highly competent engineers with 5 to 15 years of broad experience in aeronautical engineering and applied mechanics for work in the fields of super- and hypersonic aerothermodynamics and space flight technology. Primary consideration will be given to individuals capable of handling diverse problems in these fields. Send résumé to Thomas Distabile, Gruen Applied Science Laboratories, Inc., 60 Hempstead Ave., Hempstead, Long Island, N.Y.

Mechanical Metallurgist—Will be required to perform theoretical and experimental stress analyses on high-speed rotating parts, complex pressure vessels, and hydromechanical servomechanisms for jet aircraft accessory equipment. Will provide an opportunity to become familiar with programing procedures for IBM 704 and 705 electronic data processing machines. Experimental work will involve use of such tools as stresscoat, bonded wire strain gages, and photoelastic equipment. B.S. degree in Mechanical Engineering required, and graduate work or experience in theoretical and applied mechanics desirable. Please send reply to Engineering Employment Supervisor, Hamilton Standard Division, United Aircraft Corp., Bradley Field Rd., Windsor Locks, Conn.

874. Technical Writers—Major southeastern airframe manufacturer requires services of two experienced technical writers for work in editing, rewriting, publishing, and distributing data prepared by design specialists for design handbook, standard repair manuals, standards manual, and similar engineering publications. Experience on Government maintenance and flight manuals is essential; also ability to edit, clarify, and coordinate specialist's data into a standard format and arrangement suitable for company-wide publication. This is an expanding operation in the engineering division, has ample headroom; salaries are commensurate with work produced, moving expenses are covered. If interested, write for interview.

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it will be
of interest to the companies
and of benefit to the Institute if you
mention that you saw it in
Aero/Space Engineering

AERONAUTICAL ENGINEER

MS or PhD degree in aeronautical or mechanical engineering, for analytical and experimental research and development in the aerodynamic heating and heat transfer fields. Several years of applicable experience can be substituted for the advanced degree requirement.

Sandia Corporation is located in Albuquerque, New Mexico, and is engaged in research and development of nuclear weapons for the AEC. Albuquerque is a modern city of about 250,000, with an excellent climate and many cultural and recreational attractions. Summer nights are cool, winters are mild, and there's plenty of year-round sunshine. Sandia's liberal employee benefits include generous vacations and holidays, retirement and insurance plans, and a graduate educational assistance program. Paid relocation allowance.

Write to Professional Employment Section 514.

SANDIA CORPORATION
ALBUQUERQUE, N. M.

AERODYNAMICISTS

EXCEPTIONAL OPPORTUNITIES ON CHALLENGING, LONG-RANGE PROGRAMS

Bell Aircraft's expansion in three major fields has created high level positions on advanced analytical and development programs. Immediate openings include:

SPACE FLIGHT "Dyna-Soar"

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SENIOR ENGINEERS FOR:

- Gasdynamics Research
- Stability and Control
- Static and Dynamic Aeroelasticity
- Flutter

AIRCRAFT Jet VTOL

GROUP LEADERS FOR:

- Stability and Control
- Installed Engine Performance

SENIOR ENGINEERS FOR:

- Static Aeroelasticity and Flutter
- Advanced Aerodynamic Design
- Flight Control Systems Analysis
- Aerodynamic Testing
- Aerodynamic Heating Analysis

MISSILES Advanced Design

GROUP LEADERS FOR:

- Flight Control Systems
- Stability and Control
- Performance

SENIOR ENGINEERS FOR:

- Performance
- Stability and Control

Send your resumes today to learn about these assignments and the unusual opportunities they offer you for rapid advancement and professional growth. Liberal salaries and fringe benefits. And you'll find good living for you and your family with unexcelled cultural and recreational advantages on the beautiful Niagara Frontier.

Write: Supv., Engineering Employment, Dept. A-52

BELL AIRCRAFT CORPORATION

Buffalo 5, New York

Bell Aircraft Corporation is a member of the Martin-Bell industry team developing the Dyna-Soar hypersonic glider for the U. S. Air Force. Other team members are the Martin Company, Bendix Aviation Corporation, Minneapolis-Honeywell Regulator Company, Goodyear Aircraft Company and American Machine and Foundry Company.

BELL Aircraft CORP.

Available

885. Technical Librarian—Experienced in inaugurating and managing company technical libraries, preparation and publication of technical bibliographies, etc., in Great Britain. Desires similar position in U.S.A. College graduate; female; age 30; other language, French. Available in January.

883. Sales Engineering—Sales and engineering liaison in the West Coast area. Extensive experience in the aviation industry involving management, production, engineering, and sales, as well as military contractural background. Good acquaintance in the industry. Résumé on request.

882. Aeronautical Engineer—Age 26. B.S. in A.E. Extensive experience in administrative work, with a good college background in all phases of aeronautical engineering. Interested in technical representative, liaison or production engineering, or similar position. Free to travel and willing to relocate. Complete résumé on request.

881. Engineer—Administrator—M.S. in Ae.E. (M.I.T.). Technical management experience includes 3 years as Chief, Research & Development Branch, Division of Military Application, Atomic Energy Commission; 2 years as staff supervisor of research and development for propulsion of guided missiles; 2 years as commander of aviation technical school; 1½ years as head of aircraft overhaul and repair department; 1½ years as commander of aircraft groups. Now a Colonel with over 20 years' experience in military aviation. Desires change to technical administrative work in industry or field of education. Available January 1. Current pilot qualifications include jet fighters and multi-engine transports. Age 46. Detailed résumé forwarded upon request.

880. Special Assignments Engineer—Seeks challenging position assisting a busy VIP. Can assume responsibility and get things done. Excellent on reports, keen analytical mind, and appreciates the value of the business dollar. B.S. in Mech. and Aero., M.S., in Aero. Work history begins June, 1948, as test engineer—1 year; commercial sales representative—1 year 8 months; research engineer—4 months; product application engineer—3 years 4 months; senior field engineer—3 years; manager and partner in own manufacturing business (ten men) for 6 months. Age 33.

879. Executive of Management Assistant—Extensive high-level experience in aviation industry, in engineering, management, and executive positions. Graduate aeroengineer with unusual combination of abilities in technical, management, and business aspects. Current in all disciplines of astronautics; capable of forming and directing Space Division, or as Assistant to President of Vice-President; Director of Advanced Planning, Research and/or Development. Correspondence strictly confidential.

878. Washington Representative—Experienced (including 7 years as Washington Representative for large aircraft company); energetic, effective; mature judgment and high excellence. Proved abilities include sales-engineering, contracts, general business, and ethical scouting. Wide range of contacts. B.S. Aero. Versed in the latest developments of aero, missile, and space technologies, including AE, MHD, etc. Seeks major responsibility as Washington Representative of sizable company needing improved results. Résumé on request. Mutually confidential.

877. Teacher of Aeronautical Engineering—B.A., M.E. Age 54. Ten years in teaching aerothermo-fluid dynamics; jet engines; strength of materials; airplane design and performance. Twelve years in research and design.

876. Sales Engineer—B.S.M.E., 1948. Former Air Force Pilot Instructor. Five years in WADC-AMC Laboratory and project office work. Last 4 years with same company as top productive sales engineer on electromechanical airborne equipment. Desires position of greater responsibility and promise. Los Angeles area only. Please provide general job description in your reply.

The number preceding the notice represents the Box Number of the Institute of the Aeronautical Sciences to which inquiries should be addressed.